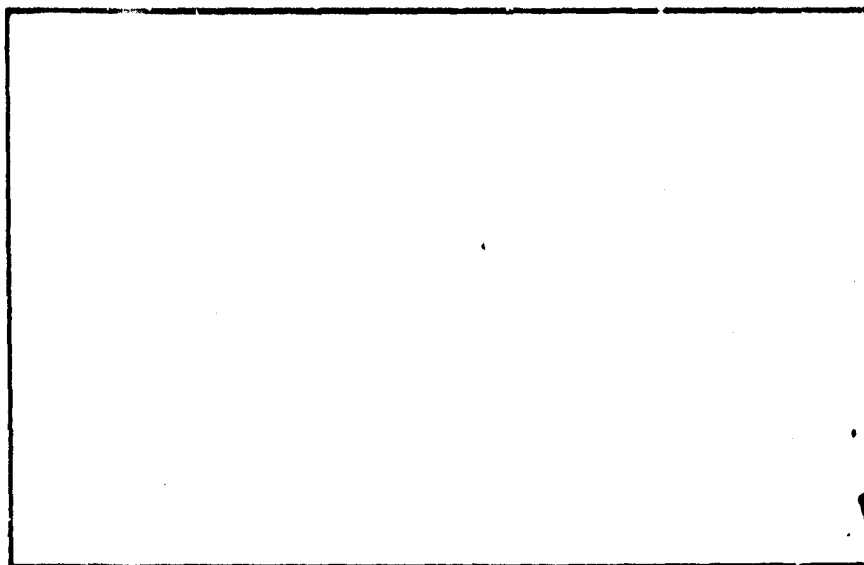


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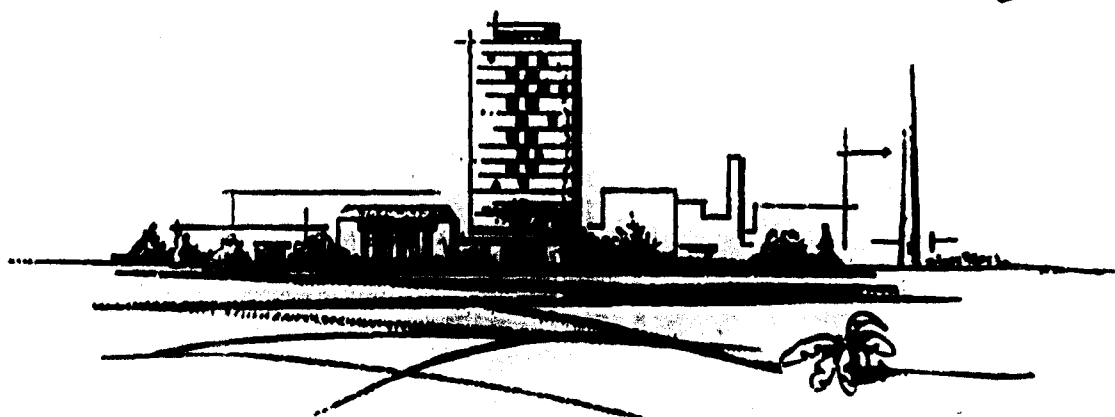
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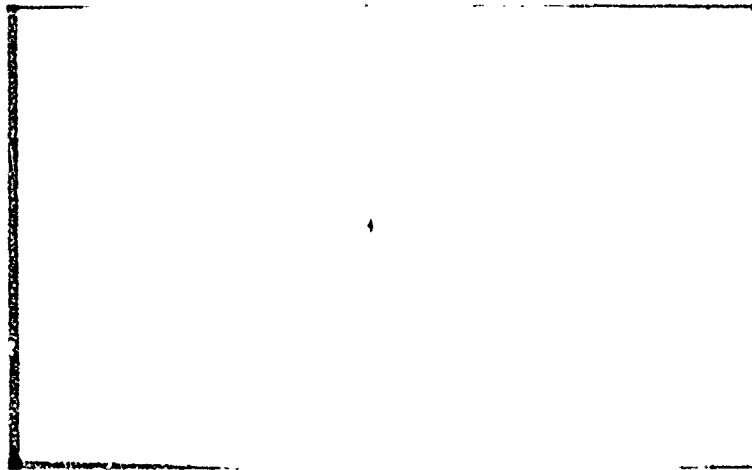


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DETAILED ANALYSIS AND DESIGN REVIEW  
OF THE MARK IX (MODIFIED) UNDERWATER  
BREATHING APPARATUS,

to

UNITED STATES NAVY  
EXPERIMENTAL DIVING UNIT -  
Contract No. N00014-66-C-0499

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July 30, 1969

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J. M. Tierney — C. T. Marr

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DETAILED ANALYSIS AND DESIGN REVIEW OF THE  
MARK IX (MODIFIED) UNDERWATER  
BREATHING APPARATUS

by

J. M. Tierney and C. T. Marr

INTRODUCTION

In October, 1968, as part of the program to modify the Mark IX Underwater Breathing Apparatus, Battelle Memorial Institute, Columbus Laboratories, conducted a limited review to identify potential problem areas. <sup>(1)</sup> That effort called for a more extensive and detailed review, the results of which are presented in this report.

The Mark IX apparatus has been reviewed in detail primarily to determine those design features that

- May endanger the lives of its users or handlers
- Do not adequately satisfy their functional requirements within the overall design context
- Constitute shortcomings in materials selection or design assembly.

That is, the review constituted an attempt to find fault with the apparatus, its components, and its parts. This review was based on examination of Mark IX units, contacts with component suppliers, and information obtained from design drawings, parts catalogs, and service manuals.

In order to consider potential dangers from the direst viewpoint, possible consequences, rather than probable consequences, were considered for the various design shortcomings or parts failures. For instance, failure or malfunction of a part may be suggested as possibly resulting in a leakage of breathing gas which possibly may be fatal to the diver. However, many of the possible fatalities that are suggested as possible consequences of equipment failures are unlikely to occur. Diver training and response will avert catastrophe in many instances. In others, failures in use will be non-catastrophic, although serious.

This report is divided into five major sections, presented in the following order:

Summary and Conclusions. This is a general summation of the review and its findings. A table is presented, showing component or part, design fault, and recommendation or remarks.

General Review. In narrative form are presented a description of each component and its function, the controls or tests applied to the component during its manufacture or assembly, the critical or potential-failure areas of the component, and recommendations for improvement or elimination of potential failures, or remarks concerning the component.

Failure Mode and Effect Analysis. The analysis is presented in tabular form and lists components and subcomponents or parts, the mode of possible failure, the probable cause of the failure and its possible result and effect on the diver, counteraction that can be taken by the diver, and recommendations or remarks.

Design Verification. This section consists of three tables: engineering analyses or technical considerations that should be applied; pressure, flow, and leak tests that should be performed; and physical tests that should be conducted. Each table lists the applicable component or subcomponent and whether or not the analysis or test has been completed.

Maintainability. This section deals with lubricants and cleaning methods applicable to breathing systems. Tables are presented showing comparison of lubricants, cleaning agents used in oxygen service, and suggested cleaning methods for Mark IX components.

The Mark IX system was reviewed over an 8-month period. During that time, several modifications were made in the apparatus. These changes may not be reflected in this report, and certain critical or failure-prone areas that are listed may already have been eliminated.

This design review was conducted within the Mechanical Engineering Department of Battelle's Columbus Laboratories, under Contract No. N00014-66-C-0199. LCdr. William Milwee of the U. S. Navy Experimental Diving Unit was the project officer.

### SUMMARY AND CONCLUSIONS

The general design of the Mark IX (Modified) Underwater Breathing Apparatus is adequate for the purpose to which the unit is being put. However, because of the limited production and use of the apparatus and its developmental configuration, more caution must be exercised in its use than with other units having a longer history of successful operation. It is the developmental nature of the unit that contributes most to its potential dangers. There is a tendency to extemporize, to use parts not designed for such a life-support system, and to modify components piecemeal. The result is a collection of components that provide underwater breathing capability rather than a polished-design breathing system.

The ability to use off-the-shelf items is attractive because of the convenience and, usually, the lower cost of such items as compared with specially ordered items. However, off-the-shelf items probably have not been certified specifically for the use to which they are put. Also, any one off-the-shelf item is not necessarily identical to the previous, apparently identical, off-the-shelf item. That is, the form, size, and function as envisioned by the manufacturer may be the same, but the materials of construction may not, and "improvements" may have been made in its operation that result in different functional characteristics when it is used in the present overall design context.

The faults found with the apparatus were, for the most part, minor. However, a minor fault or malfunction in a life-support apparatus is potentially more serious than the same type of fault or malfunction in a different apparatus. Also, users of such apparatus, particularly diving apparatus, tend to become complacent with its continued use, making minor problems all the more hazardous.

The primary faults in the design of the Mark IX Breathing Apparatus are summarized in Table 1. All faults should be corrected, but those blocked in with dotted lines certainly should be corrected before additional procurement, and those blocked in with solid lines should be corrected in existing units, as well as in future units.

There are possibilities for failure of the apparatus not necessarily due to design. For example, fatigue of springs may occur during normal operation; elastomeric parts such as O-rings may leak because of age, use, or handling-imposed cracking or deterioration; components may leak because of negligence in fastening couplings. Such potential failures, while not due directly to design, are related to design in that failure-prone areas may be avoided by design practices. Failures such as those suggested above are considered in the General Review of the apparatus, and in the Failure Mode and Effect Analysis.

This review has led to the conclusion that the Mark IX (Modified) Apparatus is operationally acceptable in its present design configuration, but only with the provision that the setup and prediving-checklist procedures, as presented in the Mark IX Service Manual(2), are followed prior to each use of the apparatus. Further, certain design features must be changed as soon as possible, but definitely prior to further procurement. These are features that, in conjunction with potential human error, pose dangers to the users of the system. Other features, while not definitely endangering lives, also should be changed because they may contribute to a potential malfunction.

All components used, or to be used, in the Mark IX apparatus should be specified, tested, and placed on the Navy's Qualified Parts List. This will insure that components for subsequent units will meet the requirements and needs as presently envisioned for the Mark IX. "Improved" components then would not be used inadvertently in future Mark IX units.

### GENERAL REVIEW

The Mark IX (Modified) Underwater Breathing Apparatus has been reviewed for the purpose of discovering potential failures in components and parts and their effects on the apparatus and its users. Included in this review was a consideration of the function of each piece of apparatus, and whether this function was adequately performed. This

TABLE 1 SUMMARY OF DESIGN FAULTS IN THE MARK IX APPARATUS

Component/Part	Primary Faults	Conclusions/Remarks
Backpack	Alignment (ake split case edges, lack of backup plates for toggle clamps) may cause case fracture interior hardware scratches coated surface of emergency cylinder	Faults are minor and easily corrected; however, scratching by hardware is serious
Emergency Cylinder	Depends upon protective coating for corrosion resistance, and coating is easily scratched cylinder is not DOT-approved	Cracks can result in stress cracking lower pressure outlets are DOT approved
Valve Stem	Extension through bottom of backpack makes valve susceptible to damage	Valve can be designed to operate from side, or cover can be attached
Pressure Regulator	Outlet pressure increases as cylinder is depleted must be set for specific mission depth	Regulator better suited to diving operations can be used
Flow Control Block		
Demand Regulator	Unbalanced design results in increase in outlet pressure as inlet pressure increases	Regulator can be designed for balanced operation
Orifice Assembly	Orifices are interchangeable on, and removable from, retainer assemblies possible to have incorrect size, or missing, orifice (a)	Orifice and retainer can be built as one unit with external identification as to size
Canister	May be used when empty or when containing exhausted Baralyme (a)	Method needed to show both presence and condition of Baralyme without removal from backpack
Heating Blanket	Electrical lead-ins are not securely anchored to canister, and mated electrical plugs invite use as lifting handle lead-ins may be broken or pulled out	Secure, insulated anchor is required
Heating Jacket	Heat is lost to the sea at least as rapidly as it is transferred into the canister	Exterior of the jacket canister assembly should be insulated
Filler Cap	Spring plate turns as cap turns, grinding the Baralyme	Spring should be designed to turn freely in the cap
Breathing Bags		
Drain Caps	Caps are attached, out of sight, in vest pockets and may be overlooked in preliminary setup	Possible to enter water with caps off, easier method of capping and checking required
Mouthpiece/T Assembly		No design faults, although handling procedures may produce failures
Exhaust Valve		No design faults, although pressure range requirements of diver should be checked
Vest	Bag pocket design requires tugging on bags to insert them in pockets possibility of tearing bags	Bag pockets should completely open from fronts or sides for easy insertion
Demand Breathing Unit		
Whitely Cutoff Valve	Can result in excess pressure at demand hose, possible bursting, if regulator leaks while valve is shut	Valve with pressure-relief capability should be used
Fittings/Connectors		
Nipple from Pressure Regulator	Incorrect nipple was used in at least one case (non corrosion-resistant) with result that rust fell into control block	Adherence to design requirements, rather than convenience, should govern assembly of apparatus
Coupler and Elbows at Control Block	Tapered pipe threads require the use of thread sealant, Teflon tape shreds and particles fall into control block	Straight-threaded fittings and O-rings would be preferable
Elbows at Control Block	Elbows in use are not rated for the pressures used	Fittings should be obtained to meet functional requirements
Hoses		
Umbilical Supply	Hose is not anchored to apparatus except by connection to control block, pull on hose may dislodge components, cause leaks	Secure anchor to case should be provided
Demand Flow	Hose is not anchored to apparatus except by connection to control block, pull on hose may dislodge components, cause leaks	Secure anchor to case should be provided
Liter Flow	Hose is made up "on the spot" without pressure proof test	Material and rating of hose/fittings should be specified, hose assembly should be tested

(a) These are more operator faults than design faults in that strict adherence to prediving setup and checklist procedures should prevent their occurrence. However, design changes can lessen the possibility of the occurrence of these two operator errors coming about through accident or negligence.

General Review is an overview of each major component of the apparatus. It is the broad base from which details were explored. As such, it is the basis for the more detailed review encompassed by the Failure Mode and Effect Analysis.

### Mark IX (Modified) Underwater Breathing Apparatus

The Mark IX (Modified) Underwater Breathing Apparatus is designed to operate as a semiclosed-circuit, mixed-gas breathing apparatus, with breathing gas supplied through an umbilical hose from a source external to the apparatus. In an emergency, the apparatus may be used in the open-circuit demand mode with the umbilical supply, or a reserve gas cylinder, carried as a part of the apparatus, may be used as the emergency supply in either the semiclosed- or open-circuit mode.

The major components of the apparatus are the reserve-gas cylinder; a pressure reducer-regulator connected to the cylinder; a flow-control block through which all the breathing gas passes and which contains a first-stage regulator for the demand breathing unit; a demand breathing unit consisting of a second-stage regulator and a mouth-piece; a canister for holding carbon dioxide absorbent; inhalation and exhalation breathing bags; an exhaust valve to regulate and relieve system pressure; and either a rebreather mouthpiece or a helmet assembly.

### Backpack

#### Description

The backpack is a streamlined case especially designed for the Mark IX unit. It contains and supports the gas-purification canister, the Mity-Mite emergency-gas pressure regulator, the emergency-gas cylinder, and the flow-control block. Originally constructed in one piece, the unit has been modified to a case and cover, secured together by means of four metal toggle clamps.

The emergency cylinder is held inside the case by means of a clamp and a bracket that is attached to the case with two screws. The canister is held inside the case by means of a spring-loaded retaining cable. The pressure regulator and control block are not secured to the case, but are retained in place by a yoke assembly between the cylinder and regulator, by a quick disconnect fitting between the regulator and the control block, and by the canister pressing against the control block.

There are four circular holes in the bottom of the case for drainage and for access to the emergency-cylinder valve handle and the control-block purge-valve handle, and a hole in the side of the case for access to the emergency-cylinder clamp screw.

The backpack is secured to a nylon diving vest by means of a brass rod and six snap fasteners. The L-shaped rod has a 3-inch leg on one end, and is retained by fitting this leg down inside the case.

The case and cover are fabricated of glass-fiber-reinforced polyester, using standard methods of hand lay-up. Individual one-piece units have been handmade by a local (Buffalo, New York) job shop under contract to Scott Aviation and modified by Battelle-Columbus.

### Manufacturing/Assembly Controls and Tests

After fabrication, each unit receives a visual and dimensional check by Scott. After modification, i.e., splitting into two pieces, and the addition of four stainless steel toggle clamps and eight stainless steel alignment tabs, the unit receives a visual and dimensional check and an inspection to insure that the clamps are secure and that they adequately fasten the cover to the case.

### Critical Areas

The toggle clamps are attached to the case and cover with no reinforcing backup plates where attaching screws penetrate the fiber-glass walls. Case breakaway probably will occur at these areas.

All hardware and attaching screws are stainless steel. However, stainless steels are susceptible to stress corrosion in ocean environments, as well as to crevice corrosion in seawater. Different types of stainless steels have different corrosion susceptibilities. The steel types used in the case, and thus their corrosion susceptibilities, have not been identified.

Snap-fastener eyelets are attached through the wall of the case without reinforcement. Continued use may result in fracture of the plastic near the snap, with subsequent gross fracture of the cover and/or pull-out of the eyelet.

Snap fasteners on one of the cases examined were not corrosion-resistant material, but depended upon paint for protection. As the paint flaked off, the snaps rusted. They will corrode either to the point where continued use results in breakage, or to the point where they pull out of the case. Corrosion may be accelerated because the matching halves of the fasteners, attached to the vest flap, are brass.

The screws used to attach spacers and the bottle-retaining sleeve are countersunk in the case walls. The thinness of the walls and misalignment of holes result in the screw heads digging into the walls, cutting and delaminating them. Misalignment also results in the screw heads being canted, with a sharp edge rising above the flat surface of the case. This edge may snag or damage other items.

The bottle-retaining clamp (Suretite) is a strap that is tightened by means of a screw assembly. This screw assembly is spot welded to a portion of the strap and, although the material is "stainless", rust has appeared in this area. The spots possibly were not passivated after welding.

The cover is mated to the case using alignment guides. However, these guides are so designed that no play is allowed to position the cover, with the result that the guides split the edges of the case, compounding the difficulty in attaining alignment.

Although each unit is subject to visual and dimensional inspection, there is no set inspection standard for number and type of defect or acceptable/rejectable dimensional deviation. Nor is there a specified crushing load that the case must sustain.

SUMMARY REPORT

on

DETAILED ANALYSIS AND DESIGN REVIEW  
OF THE MARK IX (MODIFIED) UNDERWATER  
BREATHING APPARATUS

to

UNITED STATES NAVY  
EXPERIMENTAL DIVING UNIT  
Contract No. N00014-66-C-0199

July 30, 1969

by

J. M. Tierney and C. T. Marr

BATTELLE MEMORIAL INSTITUTE  
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505 King Avenue  
Columbus, Ohio 43201

The backpack has to be handled frequently and, therefore, is subject to dropping, both empty and loaded, with consequent damage to the case and/or cover, misalignment of cover, stress on toggle clamps, misalignment of components inside, and mechanical-shock damage to those components.

#### Recommendations/Remarks

Because of the limited number of backpacks produced and the hand-operation character of the fabrication procedure, there is no standard qualification test applied to the backpack. There is no guarantee by the manufacturer that materials or methods will not be changed. At the least, before acceptance of a backpack, the supplier should be required to attest that a representative sample has passed crushing and drop tests.

Drop tests should be performed on representative samples both with the backpack empty and with loads simulating the weights and locations of the components normally contained within the backpack. The acceptable types of defects should be specified, as well as the crushing (compression) weight that the backpack must sustain without fracture of the case or cover, damage to the toggle clamps, or misalignment of the cover on the case.

Positioning guides should be redesigned to eliminate damage to the case. Although these may be nylon strips bolted to the edges of the case, they would be more satisfactory as an edge or lip cast in place during fabrication of the case. This would eliminate damage to, and corrosion cells with, the cylinder and canister by bolt heads or nuts.

Metal backup plates should be used to reinforce the toggle clamps, both on the case and on the cover. These should be of the same composition as the toggle clamps. The material for the clamps, plates, and bolts preferably should be an alloy chosen specifically on the basis of seawater serviceability. Backup plates may be "cast in place" during layup, or may be threaded to accept attaching screws, thus eliminating the need for separate nuts.

The stranded wire cable used to hold down the canister is susceptible to crevice corrosion, and should not be of austenitic or ferritic stainless steel.

Reinforcing plates should be provided for the snap-fastener eyelets to distribute the fastening and unfastening loads over a larger surface area of the case and cover. Plates should be galvanically compatible with the snap material. Snaps should be corrosion resistant and compatible with snap halves attached to the vest.

#### Emergency-Gas Cylinder

##### Description

The emergency-gas cylinder is a 150-cu in., 3000-psi-service-pressure bottle manufactured by Walter Kidde Company. It is made of drawn 4130 steel with a welded-on top. A valve assembly is attached to the cylinder by means of a threaded

adapter. The threaded adapter has 1-5/16 - 12 threads on one end that mate with the steel cylinder. A standard 1/2 - 14 NPT thread is provided in the fitting for attachment with the valve assembly. A rubber O-ring between the threaded adapter and the cylinder prevents high-pressure gas leakage.

The valve assembly is a modified Type K diving valve. A safety-cap boss has been brazed to the body of the valve and a tap made into the high-pressure side of the valve. A safety-cap assembly is threaded over the boss that houses a 3800-psi shear-type frangible safety disk. A condensate tube is attached to the end of the valve that fits into the cylinder to help exclude moisture from the system. A valve plug with a nylon seat is threaded through the center of the valve body to close off the high-pressure gas. A valve stem keyed to the valve plug drives the plug. The valve stem is positioned and sealed by a packing nut in the valve body. A compression spring bearing against the valve body and a flange on the valve stem forces the valve stem into the packing nut. The pressure outlet is on a flat surface of the valve body for connection into a pressure regulator (Mity-Mite). A seal is effected on this surface with an O-ring.

The cylinder is held inside the backpack by means of a sleeve and a clamp that is attached to the case with two screws

This cylinder is a modified Kidde item (Kidde Part Number 240959, modified) in that it does not have the internal coating usually applied for oxygen service, and is shipped from Kidde with only a primer external coating. Scott Aviation takes care of providing internal and external coatings. (3)

#### Manufacturing/Assembly Controls and Tests

The bottle was designed originally as a 3000-psi pneumatic unit for life-raft inflation, and was built to Specification MIL-R-8573. However, the modified bottle, as used in the Mark IX apparatus, does not meet, nor is it manufactured to, this specification. Also, this size bottle (volume/pressure) does not have Department of Transportation approval and can be shipped across state lines only when it is specified for military use. (3)

Each bottle is hydrostatically tested to 5000 psi and has a theoretical burst pressure of 6667 psi.

#### Critical Areas

The steel used for the cylinder (4130) is susceptible to corrosion and must be protected by a coating. However, coatings usually are easily damaged and a scratch through the protective covering will result in severe localized corrosion. Such corrosion may extend under the coating on contiguous areas. Corrosion in the case of gas-containing cylinders is particularly dangerous because of the high tensile stresses generated in the external surface by internal pressurization. This combination of corrosion and high tensile stress may result in stress-corrosion cracking.

Hardware in the backpack is located such that the cylinder coating is severely scratched, giving rise to rusting and the possibility of stress-corrosion cracking.

Galvanic corrosion, with accelerated rusting of scratched areas, may occur also because of the electrochemical dissimilarity between the hardware and the bottle substrate. Such rusting also may take place between the neck of the bottle and the valve adapter. In this area, crevice corrosion may occur. The interface between scratched areas on the bottle and the sleeve securing the bottle also is susceptible to crevice corrosion as are the areas under the heads of the screws that secure the mounting bracket to the case.

The valve handle has been designed to extend through the bottom of the case so that the diver may initiate and regulate emergency-gas flow. However, the valve, in this location, is exposed to accidental blows that may damage the valve and/or result in a malfunction during emergency use. This location is such that, if the diver sits while wearing the apparatus, the valve may be damaged or the connection between the pressure regulator and the control block may be stressed.

The bottle is not DOT-approved and is not, therefore, certified as meeting the stringent requirements imposed for oxygen service. Nor is the bottle a "standard" size that is easily procured.

#### Recommendations/ Remarks

The possible use of a different material for the cylinder should be investigated. One of the requirements should be reduced corrosion susceptibility in seawater. Materials design also should extend to the selection of compatible materials for attachments, fittings, and hardware.

Hardware for positioning and securing both the cylinder and the backpack cover should be located so that it does not damage the cylinder. Handling care also should be specified for the coating, itself.

In order to meet DOT requirements, and to assure stricter procurement rules, a standard-size bottle may be used. This may require the acceptance of a lower working pressure and, thus, a shorter operating time. Minimum and optimum acceptable operating times should be determined and pressure/volume requirements should be calculated in order to specify a standard bottle.

A new location for, or a means of protection of, the valve handle should be investigated. Possibilities include a valve handle extending through the side, rather than through the bottom, of the case or a easy-opening enclosure for the present valve handle.

#### Emergency-Gas Pressure Regulator (Mity-Mite)

##### Description

The Mity-Mite (Grove Part Number 94W) is a gas-controlled, dome-type unit that is used in the Mark IX apparatus to reduce and regulate the pressure from the emergency-gas cylinder to the flow-control block. It is attached to the cylinder-valve

assembly through a yoke assembly, and to the control block by means of a quick-disconnect fitting. It is not secured otherwise within the backpack.

The Mity-Mite originally was designed by the Grove Valve and Regulator Company for use with flame throwers, but there have been many adaptations of the original design for various users. (4)

The interior of the regulator ordinarily is Type 416 stainless steel, although a comparable regulator in Type 303 stainless steel is available. (4) The exterior of the case is available either in 303 stainless steel or in Dural (aluminum alloy). (5) The unit used for the Mark IX is Type 303.

The valve spring and diaphragm spring are 18-8 stainless steel, while the push rod, needle valves, and poppet are Type 416 stainless steel. The valve seat is an assembly of stainless steel with a nylon or Kel-F valve-seat seal. The diaphragm and O-rings are nitrile synthetic rubber manufactured in Grove's own plant. (4)

In setting up the regulator, the dome is set to a pressure slightly higher than outlet pressure. A sensing passage within the regulator exposes the underside of the diaphragm to the downstream line pressure. When the downstream pressure falls below the set outlet pressure, dome pressure acts on the upper side of the diaphragm and opens the inlet valve against its spring to maintain the set pressure. When flow is stopped, downstream pressure will rise, overcome the dome pressure, and close the valve. In case of diaphragm rupture, the regulator will fail closed. (5)

#### Manufacturing/Assembly Controls and Tests

After manufacture of parts, the Mity-Mite is cleaned and assembled under "clean-room" conditions. Cleaning is to Grove's Specification WC-2 (Superclean), which is the same as MFSC-SPEC-164, except that no nonvolatile-residue analysis or acidity checks are made. (4) Parts are never handled with bare hands. The assembled unit is functionally tested within the clean room. (5)

All synthetic-rubber parts used in the Mity-Mite are produced by Grove. Representative samples are tested for resilience, strength, flexibility, and swelling resistance. Individual O-rings and diaphragms are inspected visually for defects before being released for use in a regulator.

#### Critical Areas

The Mity-Mite valve is unbalanced, with the result that a change in inlet pressure will produce a change in the controlled, or outlet, pressure. For each 100-psi decrease in inlet pressure, the controlled pressure will increase 2.6 psi. Use of the Mity-Mite with the emergency cylinder will result in a steady increase in pressure to the control block as the emergency gas is used and as cylinder pressure decreases.

The stainless steels used in the Mity-Mite include Types 303 and 416. (4) While Type 303 is an austenitic steel with adequate chromium to insure passivity, Type 416 is a martensitic steel with much less chromium, although with at least enough to

produce passivity. However, Type 416 apparently has been chosen for its hardenability as well as for its stainless quality. But neither steel was chosen specifically for seawater duty.

The eight screws that secure the body to the dome are cadmium-plated steel. These screws were chosen on the basis of strength. And, as long as the cadmium plating remains intact, they have adequate corrosion resistance by themselves. However, cadmium is anodic to stainless steels in seawater and, as such, is prone to corrosion. (6) In addition, cadmium plating may have faults, so that substrates are exposed. In either case, the loss of plating integrity exposes the steel screws to corrosion, particularly to crevice corrosion and potentially to stress-corrosion cracking. This creates a hazard for personnel who adjust the regulator, as well as to the divers, because of the high internal pressure of the regulator.

The Snap-Tite nipple (BPHN4-4M) located at the outlet to the control block has, on occasion, been replaced by a steel nipple. This part, located between two more cathodic massive components, has severely corroded. Corrosion has introduced the potential problems of gas leaks, separation of regulator and control block, and corrosion debris falling into the regulator or control block.

The Mity-Mite regulates only the gas from the emergency cylinder and probably will be used only when the umbilical supply fails. Therefore, if the diaphragm should rupture, the fail-closed feature of the regulator will deprive the diver of his only source of gas, other than buddy breathing.

#### Recommendations/Remarks

Although it has been used successfully in diving and is relatively easy to service and maintain, the Mity-Mite regulator is not necessarily the best pressure regulator for life-or-death emergency use. A different regulator could be used to provide a pressure of 500 psi over ambient pressure, provide balanced operation from 1000 feet to the surface, and provide a higher flow than that required while still giving 10 minutes use on the present emergency cylinder. The incorporation of such a regulator into the Mark IX system should be considered. The inclusion of a fail-safe, i.e., fail-open, feature also should be investigated.

Should the Mity-Mite be retained, an alloy having higher chromium content should be specified for the interior of the unit. Type 303 interior and 17-4PH parts may be suitable.

Cadmium-plated screws should be replaced with fasteners that are compatible with stainless steel in seawater. In addition, a means of sealing crevices on the unit should be investigated to prevent crevice corrosion.

It is unlikely that steel nipples will ever be used again. The correct material will be specified in future drawings.

## Flow-Control Block

### Description

The control block, designed and fabricated by Battelle-Columbus, performs the central control function in the Mark IX breathing apparatus. Gas either from an umbilical supply or from the emergency cylinder is supplied to the control block. The block delivers this gas in either the semiclosed-circuit rebreathing mode or in the open-circuit demand mode.

The umbilical-supply gas is fed through a replaceable orifice in the block. Upstream pressure on this orifice is kept at approximately twice the ambient pressure so that sonic velocity flow occurs and a constant-mass flow rate is provided.

A first-stage regulator is built into the control block to allow direct demand breathing. This regulator provides approximately 135 psi to its delivery port with an input pressure of 200 psi.

A purge valve provides a supplementary flow of gas to the system. Operation of the purge-valve lever releases gas to the orifice discharge port through the first-stage demand regulator, bypassing the flow-control orifice. When the lever is released, flow from the regulator to the orifice discharge port ceases.

The inlet, main, and retaining blocks, assembly screws, purge-valve lever and knob, and most internal parts are brass, while the purge-valve-lever pivot screw, the lever roll pin, the orifice screen, and all springs are stainless steel. O-rings are Buna-N elastomers. All internal bores are hard-chrome plated, and the purge-valve assembly and regulator piston are electroless-nickel plated.

### Manufacturing/Assembly Controls and Tests

The control block has been hydrostatically tested. While a pressure buildup to maximum has not been possible because the particular test conditions result in too high a flow through the orifice, peak pressures of 4500 psi have been applied repeatedly without failure or damage to any component. (7)

Orifice-flow tests and purge-flow tests have been performed and found to be satisfactory. The design was further verified by test on the EDU breathing machine and by dive testing. (7)

The extremely limited production rate and the handcrafted and near-experimental nature of manufacture and assembly have precluded the development of a specific, formal, quality-control program. However, each control block, in the course of fabrication, is given a dimensional and operational check.

### Critical Areas

The orifice to be used at any one time is selected on the basis of diving-mission requirements. Orifice replacement is easy, requiring only the unscrewing

and extraction of the orifice-retainer assembly. However, orifice sizes are not identified on the retainer; orifice assemblies are interchangeable on the same retainer; and it is impossible to determine, without removal of the retainer, that an orifice is in place. In this last case, it is unlikely, but possible, for a diver to use a unit that does not contain a flow-control orifice even while a retainer, that implies the presence of a correct-size orifice, is in place.

The first-stage demand regulator is designed as an unbalanced unit. That is, as inlet, or reference, pressure increases, pressure to the demand breathing unit increases. Conversely, if inlet pressure decreases, outlet pressure also will decrease.

If outflow from the liter-flow port is blocked, e. g., by a kinked liter-flow hose, pressure will build up on the downstream orifice of the first-stage demand regulator. This will cause the regulator to close tightly, to such an extent that the piston plug may be damaged. This may affect subsequent regulation once the blockage is cleared.

Difficulty has been encountered in retaining the regulator piston plug in place. Dislodgement of the plug results in loss of regulation. However, this problem apparently has been solved by lengthening the plug and seating it deeper into the stem end.

The purge-valve-lever pivot screw and the roll pin are both stainless steel and both are susceptible to crevice corrosion. Unless this results in nearly complete disintegration or falling out of the item, corrosion of these items will have little appreciable effect on operation of the apparatus. Even complete loss of the item will not be critical, but will result in some inconvenience to the diver. However, the apparatus should be designed to eliminate, as far as possible, any corrosion.

The elbow fittings at Ports 1, 3, and 4 were not designed for use with pressurized gas, but for service to 125 psi. Operational pressures exceed this, although they may fall within the burst limits of the fittings.

Neither the liter-flow port (Port 4) nor the demand-flow port (Port 3) contain check valves. In the event of a fitting or hose leak, the gas pressure within the block is depended upon to keep out water.

Holes to accommodate the screws that secure the inlet and retaining blocks to the main block are, for the most part, counterbored. Screw heads accept a common-point screwdriver. Unless the tip is the correct size, and the screwdriver carefully used, metal slivers will be shaved from the edges of the counterbores. These slivers may cut the assemblers, damage other equipment, or fall into gas passages.

Screw holes also are even and symmetrically spaced. The inlet block therefore can be secured to the main block in an inverted position.

Tapered threaded fittings are used on the control block. These necessitate the use of a thread sealant/lubricant. Teflon tape is used for this purpose. The tape has a tendency to flake and shred, with particles falling into the control block. Here they may accumulate or combine with O-ring lubricant to restrict flow or cause binding of check valves.

Eleven O-rings are used within the control block for both static and sliding seals. These O-rings are susceptible to contamination during assembly and to solvent attack during cleaning of the control block. Cleaning solvents and lubricants also may cause O-rings to swell. This swelling, in conjunction with sliding, may result in the slipping off of the 0.008 O-ring on the regulator piston.

#### Recommendations/Remarks

A method that does not require removal of the retainer assembly should be devised to indicate that an orifice of the correct size is in place within the control block. Possible methods include a one-piece orifice-"retainer" assembly and a spring insert that will indicate by its resistance to applied pressure that an orifice is in place. For this latter method, retainer assemblies must be designed to fit only one size of orifice assembly.

The demand regulator should be designed as a balanced regulator. The first-stage regulator usually used with the Titan II unit is a balanced regulator.

The plugging of the liter-flow outlet is unlikely to occur during ordinary use of the unit. However, blocking may occur during testing, and may result in damage to the piston plug. Therefore, the plug should be checked, as should action of the regulator, whenever blocking or plugging has occurred.

Efforts have been made to mount the piston plug more securely in the stem end of the piston. The latest method entailed lengthening the plug and seating it deeper into the stem end. However, this still is a press fit, and slippage may occur. In case the plug continues to slip, another, more permanent, method of securing it must be used. A nonhardening gum or resin may be applied to the inner end of the plug, epoxy cement may be used, or induction heating may be applied to fuse the nylon to the brass.

It would be difficult to seal either the purge-valve-lever pivot screw or the roll pin after installation, as there is relative motion between these items and the materials through which they pass. However, the pivot screw may be coated prior to installation, thus decreasing the danger of crevice corrosion. A preferable solution would be to use a brass screw and a brass roll pin.

Fittings expressly designed for pressurized-gas service should replace the tapered pipe fittings currently in use. Replacement with straight-threaded fittings also will permit the use of O-rings and the elimination of Teflon-tape thread sealant with its attendant shredding/debris problem.

As long as pressure within the breathing system is greater than sea pressure, water in appreciable quantity will be excluded from the control block in the event of a leak external to Ports 3 or 4. The use of check valves at these ports will not increase the safety factor against water intake because gas pressure greater than water pressure will tend to force the valves open against the sea pressure. In addition, the use of such valves may tend to restrict gas flow and/or to result in pressure buildup with its consequent effects on the pressure regulators.

To decrease the problem of metal shavings falling into breathing-gas passages, and to eliminate a potential sharp-edge danger, the fillister-head screws should be replaced with socket-head screws.

Although the inlet block can be inverted in assembling the control block, the error will be apparent when the unit is placed into the backpack and hookup to inlet lines is attempted. However, to preclude the mismatch of the blocks and the required reassembly, the spacing of the screw holes should be nonsymmetrical.

Because of the importance of the O-rings in the control block, and the effect of the failure of those O-rings used for sliding sealing, they must be handled carefully and replaced frequently. They should be carefully chosen, taking into account their resistance to swelling caused by lubricants and atmosphere. Solvents also should be used carefully. Residual organic solvent, such as trichloroethylene, even in very small amounts, may adversely affect O-rings. The resultant deterioration in properties may cause loss of sealing or may cause O-rings to be susceptible to dislodgement from the regulator piston or purge-valve stem.

### Canister

#### Description

The canister is a stainless steel container designed by the Experimental Diving Unit for the carbon dioxide-absorbing Baralyme. It has been modified by Battelle by the addition of heaters for warming the Baralyme and thus prolonging its life.

A stainless steel water jacket is located on each of the two large sides (the front and the rear) of the canister so that hot water may be passed over the surface of the canister. Water inlet temperature is limited only by the temperature of the water used in the connected hot-water suit, and may reach 120 F. Flow through the jacket is recommended not to exceed 1 gpm.

An electric heating blanket may be inserted in each jacket to take the place of the hot-water flow. The heaters are rated at approximately 280 watts at 28 volts a-c, and draw 10 amperes at this voltage. They reach a temperature of 110 to 120 F in air.

The water jacket is attached to the canister in two parts. The bottom part is screwed to the canister and permanently bonded, with the screws sealed with a high-performance thermosetting resin. The upper part of the jacket is mated to the lower part by means of an H-shaped rubber extrusion that is permanently bonded to the upper part. The upper part is attached to the canister with two screws.

The interior of the canister is divided, essentially, into three chambers by two vertical perforated plates, or screens, and one horizontal solid plate at the upper end of the canister. Approximately 8 pounds of Baralyme is contained within the central chamber by means of the screens, end plate, and a spring-loaded plate attached to the filler cap.

Gas from the exhalation bag passes into one side chamber and through one screen into the Baralyme which removes the carbon dioxide. The carbon dioxide-free gas passes through the second screen into the other side chamber and to the top of the canister. Here it is mixed with fresh gas from the control block before passing into the inhalation breathing bag.

The basic canister is weld-fabricated by a local (Buffalo, New York) job shop under contract to Scott Aviation. The water jackets are fabricated and attached to the canister at Battelle's Columbus Laboratories.

#### Manufacturing/Assembly Controls and Tests

Each unit is visually inspected after welding, particularly the inside seams, and passivated. Each is then leak tested to 5 psi and identified with a serial number.

After the water jackets have been attached, they are tested for leaks with water introduced through the inlet at a given rate. Leakage of the jacket is acceptable as long as the rate is less than 50 percent of the inlet flow.

Heating tests have been conducted wherein inlet, outlet, and environmental temperatures and water flow rate were involved. These tests were made to check the jacket design and were not conducted for each unit.

#### Critical Areas

The Baralyme must be packed tightly and settled into the canister to eliminate channels through the absorbent. However, the rectangular cross section with the consequent square corners is conducive to channel forming. Either the corners themselves serve as channels, or pellets settle into the corners after filling, leaving voids and potential channels within the Baralyme mass.

Excessive tapping to encourage settling during filling results in the production of dust. If it enters into the breathing-gas stream, the dust may cause diver nausea. The inversion of the canister to fill may increase the problem because this causes the larger dust particles to settle toward the outlet port to the inhalation bag.

The filler cap contains a spring-loaded plate that is designed to press against the Baralyme and help maintain the tightness of the absorbent packing and thus prevent channels. In securing the cap after filling, the plate has a tendency to turn also. This grinds the top layer of Baralyme, produces dust, and may cause pellet breakage. This, in turn, may result in settling of the Baralyme and the formation of voids or gas channels.

The canister must be checked prior to each dive to insure that the Baralyme is present, in full measure and in good condition. The canister must be removed from the backpack and the filler cap must be removed to make this check.

The purpose of the canister heaters, hot-water or electric blankets, is to increase the efficiency of the Baralyme and to extend the useful time of its carbon dioxide-absorbing action. The heat from water or a blanket must be absorbed by the breathing

gas and circulated within the canister for maximum efficiency. However, at least as much heat is lost to the sea as is transferred to the gas.

The screws that attach the lower portion of the water jacket to the canister penetrate the canister wall. Although these screws are sealed, an incomplete seal may result in leakage of water into the canister.

Moisture contained in the exhaled gas may condense on the cold side walls of the canister. This condensation may shorten the life of the Baralyme at those sides.

Heating blankets have electrical leads extending from the top of the heating jacket. These are not securely fastened to the canister and may be pulled out or frayed because of movement of the umbilical cable. The leads form a heavier cable that terminates in male and female plugs. However, these plugs are joined when the blanket is not in use, and the resulting configuration has the size and shape of a handgrip. Should this be used to lift the canister, pullout of the lead-ins or damage to the blankets could occur.

The heating blankets presently used have a tendency to inflate during rapid decompression. This may result in internal damage to the blanket, e.g., wire/element breakage.

Short lengths of flexible hose are attached to the exhalation and inhalation gas ports of the canister by means of metal hose clamps. One is fitted with a male screw coupling, the other with a female coupling for attaching the canister to the breathing bags. The hose clamps, although stamped "stainless", have shown areas of rust. Thus, in addition to the natural tendency of the sharp-edged clamps to cut the hoses, the clamps may fail through corrosion. Either would result in leakage of gas to the sea and possibly of water into the canister.

#### Recommendations/Remarks

The canister should be redesigned to provide more even and easier filling, easier inspection, more even heating, and reduced heat loss. Among the possibilities are: the use of a top-filled circular cylinder; nonmetallic construction with molded-in-place appendages for breathing bag attachment; scratch-resistant, transparent material; double-walled construction for hot-water circulation; heating elements embedded in the walls. Transparent material probably would require the periodic use of an ultrasonic cleaner to remove Baralyme dust from the interior walls.

If the rectangular metal canister is retained, the insulation of all exterior surfaces - canister and heating-jacket walls - should reduce condensation and extend the useful life of the Baralyme.

Insulated clamps should be used to secure the electrical cable and the canister blanket to the lead-ins. Also, the configuration of the cable should be changed so that mated plugs do not appear to be a handle.

The end of the spring from the compression plate in the filler port should be designed to fit into the cap in such a manner that it rides freely as the cap is turned. This will eliminate the grinding action of the plate against the Baralyme.

A method should be devised for determining whether the canister is adequately filled with Baralyme and the condition of the Baralyme, while the canister is in place within the backpack. In lieu of this, the canister must be made more readily accessible for inspection, without the necessity for removing gas fittings or filler cap.

The screws that secure the water jackets to the canister present a potential but minor problem. Seal failure with subsequent corrosion could increase this problem. A different method of attaching the jackets should be investigated, e. g., brazing or welding followed by passivation.

### Breathing Bags

#### Description

The breathing bags, roughly kidney-shaped, are designed to fit over the diver's shoulders, down his chest, and into long pockets in the diving vest. The inhalation breathing bag is on the diver's right, the exhalation breathing bag is on his left.

Both bags have molded-on appendages at the top rear. Screw-type fittings are attached to these appendages for securing the bags to the canister. The fitting on the inhalation bag is female, the one on the exhalation bag is male, thus preventing inadvertent switching of bags.

Also, near the top of each bag, but on the side away from the diver, are short molded-in-place appendages to which the breathing hoses to the mouthpiece (or helmet) are attached. The hoses are secured by means of metal hose clamps.

A male-threaded drain opening is located at the lowest point of each bag. The bags are reinforced in this area to reduce tearing. The caps for the drains are attached to the vest, inside of the vest pockets.

The exhalation bag has a reinforced opening for installation of the exhaust valve. The exhaust valve is secured to the bag by means of a metal hose clamp.

The inhalation bag contains an anticollapse device to prevent the diver's gas supply from being cut off when he rolls onto his right side. This device is a perforated, stiff, flexible hose that runs between the inlet from the canister to the outlet to the mouthpiece breathing hose.

Prior to initiation of gas flow, the bags are collapsed within the vest pockets. As gas enters the system, because it is a semiclosed circuit, both bags tend to inflate. As the diver inhales, gas from the inhalation bag is replaced by fresh (and purified) gas from the canister. On exhalation, breathed gas is pushed into the exhalation bag and then into the canister. As the pressure within the system builds up, excess gas is vented to the sea through the exhaust valve.

As gas flows from the canister, it moves into the anticollapse hose, through the perforations, and into the inhalation bag. On inhalation, gas flows back from the bag, through the perforations, and to the breathing hose as well as directly from the canister,

through the anticollapse hose, to the breathing hose. In the event that the bag collapses, gas will continue to flow from the canister, through the anticollapse hose, to the breathing hose.

The bags are fabricated of dipped Neoprene by a local (Buffalo, New York) job shop under contract to Scott Aviation. Scott sets up the mold while the job shop handles the dipping, curing, and removal from the mold. Scott installs the necessary fittings. The anticollapse hose has been fabricated and installed by Battelle's Columbus Laboratories. The hose is a reinforced synthetic rubber.

#### Manufacturing/Assembly Controls and Tests

Manufacturing is essentially a handcrafting operation and no specific, formal, quality-control program is applied. However, visual and dimensional checks of all bags are made after fabrication. Leak tests at 1-1/2 psi are performed both before and after fittings are installed.

The anticollapse device has been tested in use and found to function adequately.

#### Critical Areas

Although dipped Neoprene is easily fabricated, inexpensive, and lightweight, it is extremely susceptible to damage such as puncture and tearing.

Metal hose clamps are used to secure breathing hoses and the exhaust valve. These clamps, although labeled "stainless", have rusted in places. Cleaning of the clamps is difficult, particularly as they are seldom removed, and continued corrosion may result in fracture of the clamps and leakage at the hose-bag or valve-bag interface. In addition, the edges of the clamps are relatively sharp and may cut into bag or hose material, especially as hoses are flexed and as the valve stem is pulled.

The drain caps are attached to the inside of the vest pockets. In this location, they are difficult to secure and, being out of sight, may be forgotten in making the equipment ready for use. Should they not be secured, or be left off entirely, water may enter the inhalation bag and/or breathing gas may escape. They would be very difficult to secure while the apparatus is in use.

#### Recommendations/Remarks

Although a less fragile material would be desirable for breathing bags, the advantages of the present bags outweigh the shortcomings of the material. In addition to previously cited characteristics, Neoprene is easily repaired in case of a puncture or small tear. Additionally, the bags are protected within vest pockets and have a history of acceptable operation. However, their acceptability would be enhanced by a new method of enclosure within the vest. The present construction of the pocket requires the application of considerable stress to the bags to position them correctly.

Hose clamps should be "insulated" from bag and hose material so that sharp edges do not result in cutting. Also, clamp material should be corrosion resistant in seawater. The label "stainless" is not adequate assurance of corrosion resistance.

Drain caps should be secured to the bags, provision should be made for extending the drain plug through the bottom of the vest pocket, or side access to the pocket should be provided. This last choice also would make easier the insertion of the bag into the pocket.

### Mouthpiece "T" Tube Assembly

#### Description

The mouthpiece "T" tube assembly consists of a mouthbit, inhalation check valve, exhalation check valve, and a "T" that contains a DIVING/SURFACE ball valve.

With the ball valve in the DIVING position, breathing gas is inhaled by the diver through the inhalation check valve. The exhalation check valve is pulled closed by the inhalation, preventing spent gas from being drawn into the mouthpiece. On exhalation, the exhalation valve is pushed open, and the inhalation valve is pushed shut by the exhaled air. With the ball valve in the SURFACE position, neither inhalation nor exhalation through the mouthpiece is possible, and seawater is prevented from entering the apparatus.

Rubber breathing hoses are secured to the inhalation and exhalation arms of the "T" by means of metal hose clamps.

The mouthpiece assembly is fabricated of rubber, corrosion-resistant metal, nylon, and Teflon. It is supplied by Scott Aviation and is used for the Mark VI, Mark VIII, and commercial apparatuses, as well as for the Mark IX.

#### Manufacturing/Assembly Controls and Tests

Both during and after assembly, the apparatus is inspected visually to insure that it is free of defects. After assembly, it also is subjected to leak testing.

#### Critical Areas

When not in use, the cutoff valve is supposed to be placed in the SURFACE position. This is not always done. As a result, foreign objects and debris may fall into the "T" assembly, where they may cause jamming of the cutoff valve or may affect operation of the check valves.

The DIVING/SURFACE valve lever is in an exposed position on the front of the "T" assembly where it is subject to potential damage in handling and storage.

Both check valves are important in preventing carbon dioxide poisoning. However, they are not readily accessible for inspection.

### Recommendations/ Remarks

A protective cover should be provided for the mouthpiece "T" tube assembly to protect it when not in use. This cover may prevent dirt, debris, and other foreign substances from entering the "T" assembly, and also may provide protection for the cutoff-valve lever.

While not accessible for visual inspection, check valves are tested for proper action prior to each dive. Frequent testing, thorough postuse rinsing, and protection from substances that may attack elastomers are adequate safeguards to counterbalance the lack of visual inspection.

### Exhaust Valve

#### Description

The exhaust valve is secured in the exhalation breathing bag by means of a metal band clamp. As the pressure within the breathing system and, thus, within the exhalation bag increases to a level above the combined ambient and valve-spring pressures, the valve diaphragm is pushed out against the spring and gas is allowed to escape from the exhalation bag. Gas flows out until the resulting pressure within the bag is less than the combined ambient and valve-spring pressures. The spring then is able to push the diaphragm back, thus shutting off the escape flow of gas.

The spring pressure may be adjusted over a range that results in the diaphragm unseating when the breathing-system overpressure is 1/4 to 1 psi. The pressure setting chosen by the diver supposedly is the one that results in the most comfortable pressure for himself.

The exhaust valve is manufactured by Scott Aviation, and is widely used on diving apparatus such as the Mark VI, Mark VIII, and Mark IX. The materials used are rubber and corrosion-resistant metal.

#### Manufacturing/Assembly Controls and Tests

Each unit is subjected to quality control surveillance during assembly and to a postassembly test.

#### Critical Areas

The exhaust valve is susceptible to damage, both in use and in storage, because of its exposed position on the exhalation bag. The valve stem may be bent, and may bind either in the open or shut position. This will result either in a constant flow of breathing gas from the valve, or in the inability to relieve excess pressure.

When the diver pulls on the valve stem to relieve pressure, the entire exhaust valve is moved slightly, relative to the exhalation bag. This flexes the bag material

adjacent to the metal clamp that secures the valve to the bag. Continued flexure, and the cutting action of the metal band may result in a leak in the exhalation bag.

The plate end of the valve stem assembly presses directly against the diaphragm. The diaphragm, in turn, presses against an opening in the bottom of the valve body. Dropping the exhaust valve onto the stem end forces the diaphragm sharply against the edge of the opening and may result in cutting the diaphragm. This may result in a gas leak through the diaphragm.

The valve is designed to open, within the range of 1/4 to 1 psi, at the pressure set by the diver. In practice, divers almost always adjust system pressure to near minimum. This indicates that the adjustment range may be too high.

#### Recommendations/Remarks

Information should be accumulated and analyzed to determine whether the range of pressure relief is wide enough and the lower limit low enough for diver comfort.

Should it be determined that diver adjustability is not required - aside from the ability to manually relieve pressure, as is afforded by the pull knob - the possibility of relocating the exhaust valve in a more protected area should be investigated. This will help avert damage to the valve during use, handling, and storage. Relocation also would eliminate damage to the exhalation bag from flexure and from cutting by the clamp ring.

### Vest

#### Description

The vest is designed as the support/carrier for the Mark IX apparatus. The backpack case is attached to a flap that hangs down the diver's back, extending from the shoulders of the vest. At the top of the vest, behind the shoulders, is a second flap that covers the top of the backpack case; this is secured to the case and the attaching flap by means of snaps. The breathing bags are contained in specially designed pockets on the front of the vest. Weights are enclosed in zipper-fronted pockets on each side of the vest front. The vest opens completely down the front and is closed by means of a heavy-duty nylon zipper. It is adjusted to the individual diver by means of side straps that are secured by buckles.

Except for the metal snaps, buckles, and grommets, the vest is completely fabricated from nylon materials, including the thread. It is made by a local (Buffalo, New York) job shop to the specifications of Scott Aviation. This vest is similar to those used for the Mark VI and Mark VIII units.

#### Manufacturing/Assembly Controls and Tests

Using a master model as a guide, each vest is given a visual and dimensional check. The zipper is tested for smooth operation.

### Critical Areas

The vest pockets are so constructed that it is necessary to pull and tug on the relatively fragile breathing bags to insert and to remove them. The weights, on the other hand, are provided with long zippered pockets that allow extremely easy access.

The front closure does not have a flap to protect the diver from being pinched by the zipper as he pulls it shut. While this does not present a problem when the vest is worn over an immersion suit, it may result in some pain or discomfort when the vest is worn over bare skin.

The flap that hangs between the backpack and the diver's back has had a coating, probably elastomeric, applied to the side on which the backpack rests. This coating has a tendency to crack, and it may cause deterioration of the nylon substrate.

### Recommendations/Remarks

The bag pockets should be redesigned so that the bags, with hoses attached, may be slipped into place from the front or side. An inner flap should then cover the bag and be placed between it and the pocket opening, which should be secured by means of a zipper.

A narrow flap should be sewn inside the vest on one side of the front opening. This flap then should be used to bridge the front gap when the vest is donned, thus preventing possible injury to the diver's chest when the zipper is zipped up.

The necessity for coating the vest back flap should be reevaluated. Should a coating be required, one that is durable and compatible should be chosen.

### Demand Breathing Unit (Titan II)

#### Description

The demand breathing unit consists of a first-stage regulator, a second-stage regulator, a mouthpiece containing a flush-purge valve, and a breathing hose containing a cutoff valve. The first-stage demand regulator is contained within the control block. The Titan II second-stage demand regulator and mouthpiece comprise one assembly. The cutoff valve is located approximately midway in the breathing hose.

The first-stage regulator produces operational pressures between 130 and 150 psig, depending upon the input pressure. Breathing gas at this pressure is supplied through the control block Port 3, the demand breathing hose, and the cutoff valve to the second stage regulator and demand mouthpiece.

Finger pressure or inhalation cause the unit's diaphragm to deflect inward. The diaphragm presses against a lever that withdraws a rubber-faced seat from the inlet orifice, thus permitting gas flow. Exhalation deflects the diaphragm outward, releasing

the lever. The spring-loaded stem then reseats, cutting off gas flow. Excess pressure exhausts through a rubber disk valve.

The cutoff valve was installed by Battelle, not supplied by the demand-unit manufacturer. It has been inserted in the line in order that the first-stage regulator may be connected directly to the Kirby-Morgan helmet, when the helmet is used instead of the rebreather mouthpiece.

The second-stage demand regulator/mouthpiece assembly is a Titan II single-hose regulator, modified by the elimination of the regular first-stage regulator and attaching fittings. It is a product of the W. J. Voit Rubber Corporation and is fabricated of rubber and corrosion-resistant metals. It is widely used in sports SCUBA equipment as well as by commercial and Naval divers.

#### Manufacturing/Assembly Controls and Tests

The Voit Titan II has been evaluated by the Experimental Diving Unit and has been placed on the Qualified Products List, QPL No. 24169.

A quality-control procedure has been established and is followed during assembly of the units. Each unit is bench flow-checked at surface pressure and the exhaust valve is leak checked.

#### Critical Areas

The demand breathing unit is emergency equipment and, as such, must be ready for use with the least possible delay. The insertion of a cutoff valve into the demand line, especially a ball valve such as the Whitey 43S4, may result in a delay in the use of the demand system when the Titan II unit is used. Such delay is appreciably less when the demand line is already connected to the helmet, and may be even less when a different type of valve is used.

#### Recommendations/Remarks

The Titan II is an uncomplicated unit with a good use history. Other than misadjustment, mishandling, the use of damaged or deteriorated parts, or the natural wearing out of parts, there are no major problem areas.

The need for a ball valve in the demand-flow line should be reevaluated. Probably a different, more easily operated, valve such as a push-button or lever-actuated valve would suffice.

### Breathing-Gas Lines

#### Description

Breathing-gas lines are comprised of hoses and fittings that convey breathing gas between major units.

There are five breathing-gas hoses within the system: the main-supply hose that connects the umbilical supply hose to the control block, the liter-flow hose that connects the control block to the canister, the demand-flow hose that connects the control block to the demand breathing unit, the inhalation hose that connects the inhalation bag to the mouthpiece "T" assembly, and the exhalation hose that connects the mouthpiece "T" assembly to the exhalation bag. In addition, there are two short lengths of hose, one that connects the canister to the inhalation bag and one that connects the exhalation bag to the canister. These latter are considered more as being extensions of the canister than as being separate hoses.

The main-supply, liter-flow, and demand-flow hoses are flexible, nonkinking, rubber hoses. The inhalation and exhalation hoses are flexible, corrugated, low-pressure, SCUBA breathing hoses.

The main-supply hose is a Synflex pressure hose, 1/4 inch ID, supplied by Samuel Moore, Mantua, Ohio. The liter-flow hose is a 3/16-inch-ID rubber hose, unidentified as to manufacturer or supplier. The demand-flow hose is a 1/4-inch-ID rubber hose supplied by W. J. Voit Rubber Corporation. The SCUBA hoses are supplied by Scott Aviation.

The fittings generally are of three types: standard bronze pipe fittings, threaded hose fittings, and quick-disconnect fittings.

Elbow pipe fittings are threaded into the control block (Aeroquip 45-degree, Cajon street, and Acheson street) and the canister (Acheson street). Crimp-on threaded fittings are secured at both ends of the main-supply and the demand-flow hoses and on both sides of the Whitey cutoff valve in the demand-flow hose.

One end of the main-supply hose screws directly to the 45-degree elbow on the control block and into the other end is threaded the male half of a quick-disconnect couple. One end of the demand-flow hose screws directly to the demand breathing unit, while into the other end is threaded the female half of a quick-disconnect couple. To each end of the liter-flow hose is crimped the male half of a quick-disconnect couple.

Quick-disconnect pairs are located at the following interfaces: pressure regulator-control block (Snap-Tite Nipple BPHN4-4M to Snap-Tite Coupler BPHC4-4M W/SL); main supply hose-umbilical hose (Snap-Tite Coupler SNC 3847-9 to unidentified nipple), control block-liter flow hose (Hansen Connector 189 to modified Hansen Connector 185); liter flow hose-canister (Hansen Connector 189 to Hansen Connector 180-S9); and control block-demand flow hose (Hansen Connector 189-S9 to Hansen Connector 180-S9).

There also are threaded couplers attached to the breathing bags for securing the bags to the canister. These are supplied by EDU.

#### Manufacturing/Assembly Controls and Tests

If ordered to a specific requirement, hose assemblies are tested before delivery. However, "off-the-shelf" items generally are only representative of items selectively tested under quality-control programs.

The Snap-Tite nipple, BPHN4-4M, and coupler, BPHC4-4M W/SL, are manufactured to MIL-C-51234 and to AQL standards. The Hansen 180 and 189 connectors are checked according to AQL standards.

### Critical Areas

Flexibility and resistance to deterioration, collapse, and internal pressure are all important characteristics for the hoses used in the Mark IX apparatus. On the basis of performance history, the hoses presently used apparently are adequate in these respects. However, there are two areas of concern that require further evaluation: the preparation of the liter-flow hose and the installation of the cutoff valve in the demand-flow line.

No tests have been performed on these hoses that will establish specification requirements for future procurement. The leak tightness and joint integrity of the crimped-in-place fittings on the liter-flow hose, and of the demand-flow hose with the cutoff valve fittings in place, are unknown.

Fittings, particularly the pipe fittings, have been discussed in conjunction with other components.

### Recommendations/Remarks

Environmental and pressure requirements should be established for the liter-flow hose and for the modified demand-flow hose. Hose assemblies then should be procured and tested to these requirements.

## FAILURE MODE AND EFFECT ANALYSIS

Each major component of the Mark IX apparatus was reviewed in an attempt to uncover potential failures and malfunctions of subcomponents and/or parts, the probable causes of these failures, the possible results of the failures and their possible effects on the diver, action that could be taken by the diver, and recommendations for eliminating the cause of failure.

Many of the potential "failures" are so minor that corrective action may be optional. Others already may have been corrected in the steady course of design improvement and correction. However, there are others that, while minor in themselves, may have serious, even fatal, consequences for the diver in deep water.

An example of the above type of "failure" is one that results in a leak and, therefore, a loss of breathing gas. Leaks anywhere in the system are of two levels of seriousness. The most serious is a leak while the emergency cylinder is in use. Such a leak may result in diver fatality if the cylinder is the only gas source available to the diver. The less serious leak is one of umbilical gas. This may result only in wasting gas, although it, too, may result in diver fatality if the leak is such that pressure and flow are insufficient.

In both cases, there is little that the diver can do to correct a leak. His major recourse is to return as quickly as possible to the habitat or PTC. Unfortunately, many of the locations where a leak may occur are out of sight of the diver and he may not be aware of a leak until too late, particularly if the leak occurs in the emergency mode. Fortunately, most leaks will not occur spontaneously in use if the equipment is properly maintained and set up. Also, most leaks should be detected during setup procedures.

Another factor that partly determines the seriousness of a particular part "failure" is the diver, himself: his awareness of the developing situation, his knowledge of various alternatives, and his ability to put them into action. This factor is difficult, if not impossible, to include in an analysis such as this. Therefore, for the most part, the effect of a failure was considered from the most serious standpoint without crediting any probable corrective action by the diver.

Many of the "failures" noted in this analysis are detectable prior to use of the equipment, in a proper prediving setup procedure or prediving check. However, the result of the failure and its effect on the diver are reported as if the "failed" item were undetected. This is in line with the reasoning that the most severe appraisal of the equipment will lead to greater safety in its use, and may result in more thorough and critical prediving procedures.

The analyses of failure modes and effects are reported in Table 2.

### DESIGN VERIFICATION

Good design requires that a part (1) be capable of adequately performing its function within the overall design scheme, and (2) be expected to perform its function for a predictable, or reasonable, time.

The first of these requirements is met to some extent by the successful use of the diving apparatus. However, a thorough analysis requires that individual components be separately reviewed. This review is presented below in Tables 3, 4, and 5.

Table 3 is a checklist presentation of whether or not a component requires an engineering analysis or evaluation, and whether or not such an analysis has been performed. These analyses generally will be mathematical, although some may only be the comparison of the known characteristics of a part against its functional requirements.

Table 4 is a checklist of pressure and flow tests, indicating whether or not such tests have been performed on the specific components and/or parts.

Table 5 suggests physical tests that should be performed, and the reasons for the tests. In general, these tests are aimed at establishing requirements for later procurement.

Closely associated with the predictability or dependability of the apparatus is consistency in the use of specific materials of construction. Failures and shortcomings then may be traced to needed design improvements for the apparatus, rather than to incorrect materials selection for individual units.

TABLE 2. FAILURE MODE AND EFFECT ANALYSIS

Part	Mode	Probable Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation/Remarks
<u>Backpack</u>						
Cover or Case	Cracking	Dropping when loaded, placing heavy items (or sitting) on top of backpack.	Snagging on other objects by broken edges, pinching or abrading of hoses.			This may occur in storage or set-up, but probably not in use. Cracked covers (or cases) should be retired from use.
Alignment Tabs	Splitting of edges of case or cover.	Alignment tabs dig into edges.	Difficult to align cover on case which, in turn, encourages forcing cover down onto case with consequent additional splitting; breaking away of pieces of case and cover.			Redesign alignment devices.
Snaps	Corrosion/erosion	Incorrect material snaps used on case: dependent upon paint covering for protection.	Snap pullout or breakout, loose vest flap that may be snagged on obstruction.			This will occur gradually, not suddenly while in use. Brass snaps should be used to match the snap halves in the vest flap; the case should be designed to eliminate the need for a flap.
Toggle Clamps	Breakaway of case or cover	Small backup for retaining nuts: load distributed over small area.	Loose or unaligned cover.			This may occur in setup, but probably not in use. Larger backup plate to reinforce case cover edges and to distribute load should be imbedded in wall during layup, or separate reinforcement plate should be used.
Canister-Retaining Cable	Crevice corrosion	Use of stranded cable.	Separation of cable resulting in insecurity of canister.			This will occur gradually, not suddenly while in use. Whenever corrosion is detected, cable should be replaced; the canister should be secured by other means.
Bottle-Retaining Clamp	Corrosion	Spot welds that attach clamp and ring probably were not passivated.	Separation of clamp band and tightening ring resulting in loose bottle and, consequently, loose pressure regulator and control block.			Although separation may occur suddenly, corrosion will be gradual. Passivate spot welds.
<u>Emergency-Gas Cylinder</u>						
Cylinder Wall	Cracking	Stress corrosion due to combination of surface high tensile stress caused by internal pressure and galvanic corrosion caused by cells set up between bare areas (scratches) on the steel cylinder and the stainless steel nuts and guides on the backpack cover or rusted spot welds on the bottle clamp.	Explosion with damage to rest of apparatus if fracture is sudden, loss of emergency gas.	Fatal, if cylinder is in use and buddy system not available; possibly fatal or injurious from fragments if explosion occurs.	Buddy breathe, if possible.	Reposition all items that may scratch cylinder coating and set up a corrosion cell: periodic (1) pressure test of cylinder, (2) wall thickness test, (3) removal and renewal of cylinder coating to eliminate substrate corrosion, (4) removal of all fittings with cleaning and inspection.
	Corrosion	Defective or scratched coating.	Loss of wall thickness (localized or widespread) and consequent decreased acceptable pressure limit for the cylinder; may result in cracking.	Ditto	Ditto	Ditto

TABLE 2. (Continued)

Part	Mode	Probable Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation/Remarks
<u>Emergency-Gas Cylinder</u> (Continued)						
Cylinder Neck	Corrosion, crevice corrosion	Defective or scratched coating at interface of neck and adapter (the nut that secures the valve assembly).	Corrosion under the adapter, localized stress or a lower acceptable pressure limit may result in cracking in the localized area.	Fatal, if cylinder is in use and buddy system not available; possibly fatal or injurious from fragments if explosion occurs.	Buddy breathe, if possible.	Reposition all items that may scratch cylinder coating and/or set up a corrosion cell, periodic (1) pressure test of cylinder, (2) wall thickness test, (3) removal and renewal of cylinder coating to eliminate substrate corrosion, (4) removal of all fittings with cleaning and inspection.
Valve Stem	Deformation, jamming	Exposed position of the handle and the dropping either of the cylinder or of the assembled apparatus.	Inability to use emergency gas, leaking of emergency gas.	Fatal, if emergency necessitates cylinder use and buddy is not available.	Ditto	This may occur in setup or storage, probably not in use. It should be detected in pre-dive setup. Provide easy access cover for valve handle, or redesign so that handle is accessible from the side rather than from the bottom.
Safety Cap Boss	Cracked braze	Dropping, striking against another object.	Release of high-pressure gas with possible injury if release is explosive.			Unlikely to occur in use.
Spring	Breaking	Fatigue.	Leak around stem when valve is turned on.	Loss of emergency gas supply.		Likely to occur suddenly when cylinder is turned on.
Seat Plug	Deformation, scoring	Over age.	Valve will not shut off completely; leak into regulator, waste of gas.	Ditto		Should be detected in pre-dive setup.
O-ring (between neck and adapter)	Cracking, deterioration	Over age, solvent attack.	Leak of high-pressure gas.	-		Ditto
O-ring (in valve outlet)	Cracking, deterioration, cutting	Overuse, over age, solvent attack, pinching in assembly.	Leak at inlet to pressure regulator with increase in regulator outlet pressure.			This will not occur suddenly while cylinder is in use, it should be detected in pre-dive setup.
<u>Emergency-Gas Pressure Regulator (Mity-Mite)</u>						
Snapfitte Nipple	Corrosion	Nipple material incorrect.	Leakage of breathing gas; umbilical or cylinder supply; rust particles may enter either the pressure regulator or the control block partially plugging gas passages.			Insure that nipple is of correct material before using; material will be specified on procurement drawings.
Diaphragm Spring	Breaking	Fatigue; mishandling.	Diaphragm plate will lose its support, but there will be no discernible effect.			Replace spring, when break is discovered, during overhaul or inspection.
Diaphragm	Cracking; deterioration; rupture	Over age; solvent attack, mishandling.	Decreased outlet pressure, diaphragm rupture will cause regulator to fail closed.	Fatal, if emergency necessitates cylinder use and buddy is not available.	Buddy breathe, if possible.	This should be detected in pre-dive setup. Periodic inspection should be made and diaphragm renewed.
Valve Spring	Breaking	Fatigue, mishandling.	Increased outlet pressure from Mity-Mite and 1st stage demand regulator; possible gas leak at demand breathing unit.			Pre-failure detection unlikely.

TABLE 2. (Continued)

Part	Mode	Probable Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation Remarks
<u>Emergency Gas Pressure Regulator (Mitty-Mite)</u> (Continued)						
Dome Valve	Worn/damaged threads; valve open	Mishandling.	Leak from gas dome, decreased outlet pressure.	Fatal, if emergency necessitates cylinder use and buddy is not available.	Buddy breathe, if possible.	This will not occur suddenly while cylinder is in use. It should be detected in pre-dive setup.
Inlet Valve	Worn/damaged threads, valve open	Mishandling.	Leak at inlet valve.			Ditto
O-ring (body plug)	Cracking, deterioration	Over age, solvent attack.	Leak at body plug.			
Filter (inlet)	Plugging	Corrosion debris from bottle, dirt from assembly area plus excess O-ring lubricant from bottle.	Restricted flow, but no appreciable change.			Filter should be observed for cleanliness every time bottle is removed.
Yoke	Looseness	Setcrew not tightened when cylinder was installed.	Leak of emergency gas when cylinder is actuated, decrease in cylinder use time.			Should be detected in pre-dive setup.
Body Capscrews	Corrosion, crevice corrosion	Incompatible material, cadmium plated steel in massive stainless steel body.	Corrosion under screw heads with subsequent attack on threads, erosion of screw material with consequent strength loss and fracture of screw. May result in serious injury to personnel if fracture occurs during dome loading or regulator testing. Otherwise may result in gas leak.	Fatal if emergency necessitates cylinder use and buddy is not available. Possible injury by explosive force of failure.	Buddy breathe, if possible.	Replace screws with corrosion-resistant alloy, possibly a precipitation-hardening steel such as 17-4PH, and/or seal screw-head-to-regulator interface.
	Cracking	Stress corrosion due to stress set up by normal securing operations and pressurization of regulator, and to corrosion of screw material.	Cracking at thread roots with resultant fracture of screw with possible injury to personnel if fracture occurs during dome loading or regulator testing. Otherwise may result in gas leak.	Ditto	Ditto	Ditto
Gasket (valve seat)	Cracking, deterioration	Over age, solvent attack.	Increased outlet pressure from Mitty-Mite and 1st stage demand regulator, possible gas leak at demand breathing unit.			This will not occur suddenly while cylinder is in use. Periodic inspection should be made and gasket should be renewed.
<u>Flow-Control Block</u>						
Screws (inlet block)	Fracture	Overtightening, fatigue.	Leak at inlet block-main block interface with loss of breathing gas, possibly some water into gas stream and thus, moisture to Baralyme and decreased life of Baralyme.	Fatal, if cylinder is in use and buddy system not available, possibly fatal if moisture decreases Baralyme life to less than duration of mission.	Buddy breathe, if possible, and if leak is detected.	This may occur during assembly, but unlikely to occur in use. It should be detected in pre-dive setup.
Screws (retaining block)	Fracture	Ditto	Leakage at demand regulator with loss of back pressure on the piston and consequent increased flow to the demand breathing unit.			Ditto

TABLE 2. (Continued)

Part	Mode	Probable Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation/Remarks
<u>Flow-Control Block</u>						
Demand Regulator	Pressure varies directly with upstream pressure	Regulator is designed as unbalanced unit.	As inlet pressure increases, pressure to demand breathing unit increases, resulting in gas flow from unit, as inlet pressure decreases, pressure to demand breathing unit decreases, resulting in difficulty in use of unit.	Increased breathing difficulty as inlet pressure decreases.		Change of design to balanced type of unit as usually used with Titan II so that pressure supplied will be the same as pressure used in setup.
O-ring (008) (on stem)	Cracking, deterioration, cutting, slipping	Over age, solvent attack, pinching in assembly, tolerance between O-ring and entrance to block shaft too tight because of O-ring swelling.	Increased flow to canister (liter flow).	Possible discomfort as system pressure increases.	Relieve pressure with exhaust valve on exhalation bag.	This is unlikely to occur suddenly, and should be detected in pre-dive setup. O-rings should be replaced frequently and be kept from solvent exposure.
O-ring (019) (on cap)	Ditto	Ditto	Ditto			Ditto
O-ring (023) (at block port)	Cracking, deterioration, cutting	Over age, solvent attack, pinching in assembly.	Leakage with loss of back pressure on piston and consequent increased flow to the demand breathing unit.			-
Valve Spring	Breaking	Fatigue, mishandling.	Demand and purge flows inoperative.	Varies from discomfort in breathing to inability to breathe due to low system pressure because of purge inoperation; more likely to occur as diver attempts to go deeper, possibly fatal if demand unit must be used.	Change depth, if possible, to allow system pressure to build up, if demand breathing is necessary, buddy breathe, if possible.	Prefailure detection unlikely, although already failed spring will be detected in pre-dive setup.
Piston Seat Plug	Cutting, dislodging	Rough valve seat or mishandling, loose fit in valve stem.	Increased flow to demand breathing unit.			Redress piston seat, redesign plug attachment method.
Purge Valve						
O-ring (005) (at inner end of valve)	Cracking, deterioration, cutting	Over age, solvent attack.	Increased flow to canister (liter flow).	Possible discomfort as system pressure increases.	Relieve pressure with exhaust valve on exhalation bag.	This is unlikely to occur suddenly. O-ring should be replaced frequently and be kept from solvent exposure.
O-ring (012) (at inner end of sleeve)	Ditto	Ditto	Ditto	Ditto	Ditto	Ditto
O-ring (013) (at outer end of sleeve)	-	-	Leakage to sea.			This is unlikely to occur suddenly, and should be detected in pre-dive setup. O-ring should be replaced frequently and be kept from solvent exposure.
O-ring (005) (at outer end of valve)	-	-	Ditto			Ditto
Valve Spring	Breaking	Fatigue, mishandling.	Continuous purge once lever is pushed, until lever is pulled back overinflation of breathing bags.	Possible discomfort as system pressure increases.	Pull back on purge valve lever.	Prefailure detection unlikely, although already failed spring will be detected in pre-dive setup or check

TABLE 2. (Continued)

Part	Mode	Possible Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation/Remarks
<u>Flow-Control Block</u> (Continued)						
Valve Sleeve	Plugging of orifice	Debris (esp. Teflon scraps) from Post 4, through orifice and retainer assembly cavity.	Decrease in purge flow.			Replace pipe threads and Teflon tape with straight threaded fittings and O-rings.
Lever	Binding	Debris in pivot slot.	Sluggish operation, binding in open position, binding in closed position.	Discomfort because of difficulty to use or because of pressure buildup if lever binds in open position.	Use moderate force on lever.	Unlikely to occur suddenly in use, unlikely to accumulate debris sufficient for complete binding, cleaning should include external areas.
Pivot	Fracture crevice corrosion	Sea water under screw head or at thread roots.	Difficulty in operating, purge if screw completely breaks away.	Discomfort because of difficulty to use.	Apply pressure as direct push rather than as torquing motion.	Prefailure detection unlikely. Cracked screw may not be detected until complete break-away in use. Screw should be coated with sea-water-resistant material before installation, or replaced with brass screw.
Roll pin	Breaking	Fatigue.	Lever may swing loose within limits proscribed by case opening and pivot screw.			Prefailure detection unlikely, although already failed pin will be detected in pre-dive setup or check.
<u>Orifice and Retainer Assemblies</u>						
Screen	Plugging	Debris through inlet ports plus excess O-ring lubricant.	Decreased flow to canister (liter flow).	Fatal, as oxygen level in rebreathing system decreases.	Use demand-breathing unit.	Unlikely to occur to extent that will have appreciable effect, unlikely to occur suddenly in use. Screen should be checked frequently for cleanliness.
Orifice	Ditto	Ditto	Ditto	Ditto	Ditto	Unlikely to occur would require long, narrow (relative to screen openings) particles to clog
O-ring (010) (on orifice assembly)	Cracking, deterioration, slipping	Over age, solvent attack, tolerance between O-ring and opening too tight because of swelling of O-ring.	Increased flow to canister (liter flow).	Possible discomfort as system pressure increases.	Relieve pressure with exhaust valve on exit station bag.	This is unlikely to occur suddenly while in use. Probably will not be detected until orifice assembly is removed for inspection.
O-ring (011) (on retainer assembly)	Cracking; deterioration	Over age, solvent attack.	Leakage to sea.			This is unlikely to occur suddenly, and should be detected in pre-dive setup. O-ring should be replaced frequently and be kept from solvent exposure.
<u>Check Valves</u>						
O-rings (009)	Cracking; deterioration, cutting	Over age, solvent attack, pinching in assembly.	Leak from the port with the failed O-ring, regardless of which gas source is in use.			Ditto
Springs	Breaking	Fatigue; mishandling.	No discernible effect.			This is unlikely to be detected until block is disassembled for general inspection and/or cleaning.
Poppet (Port 1)	Binding	Debris through inlet port, portion of broken spring.	1. If poppet binds open and cylinder is in use, gas will be lost if umbilical is disconnected; 2. If poppet binds shut and umbilical is source, no gas will be supplied to diver.	1. Fatal, if return to habitat or PTC is not rapid enough or if buddy system is not available; 2. Fatal if emergency cylinder not usable.	1. Return to habitat or PTC, use buddy breathing; 2. Use emergency cylinder or buddy breathing.	This may occur in use, but more likely to be partly opened or partly closed. Binding open probably will not be detected in pre-dive setup.

TABLE 2. (Continued)

Part	Mode	Probable Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation/Remarks
<u>Flow-Control Block</u> (Continued)						
Poppet (Port 2)	Binding	Debris through inlet port; portion of broken spring.	If poppet binds shut and cylinder is in use, inad- sufficient gas will flow to diver.	Fatal, if cylinder is in use and buddy system not available.	Buddy breathe, if possible.	This may occur in use, but more likely to be partly opened or partly closed. Binding open prob- ably will not be detected in pre- dive setup.
<u>Fittings</u>						
Elbow (45 deg) (at Port 1)	Leaking	Thread wear; looseness.	Leakage of umbilical gas.			This will not occur suddenly in use, and should be detected in pre-dive setup.
	Cracking	Pressure excessive to part capability.	Ditto	Fatal, if cracking is sufficient to decrease gas flow below accept- able limit.	Use emergency cylinder.	Other fitting should be used.
Elbow (Street) (at Port 3)	Leaking	Thread wear; looseness.	Leakage of demand- breathing gas.		Buddy breathe, if possible.	This will not occur suddenly in use, and should be detected in pre-dive setup.
	Cracking	Pressure excessive to part capability.	Ditto	Fatal, if cracking is sufficient to decrease gas flow below accept- able limit.		Other fitting should be used.
Elbow (Street) (at Port 4)	Leaking	Thread wear; looseness.	Leakage of liter-flow gas.			This will not occur suddenly in use, and should be detected in pre-dive setup.
	Cracking	Pressure excessive to part capability.	Ditto	Fatal, if cracking is sufficient to decrease gas flow below accept- able level.	Use demand- breathing unit.	Other fitting should be used.
Coupler (at Port 2)	Leaking	Coupling was not locked and apparatus was severely jarred.	Leakage of gas, regardless of source.	Fatal, if separation of coupling and regulator occurs while cylinder is in use.	Buddy breathe, if cylinder was only source.	Should be detected on pre-dive check.
	Ditto	Thread wear; looseness.	Ditto			This will not occur suddenly in use, and should be detected in pre-dive setup.
Connector (at Port 3 Street Elbow)	Leaking	Ditto	Leakage of demand- breathing gas.			Ditto
Connector (at Port 4 Street Elbow)	Ditto		Leakage of liter-flow gas.			
		Connector was not locked and liter- flow hose was tugged.	Leakage of liter-flow gas and leakage of water into canister.	Fatal, if separation of connector and hose fitting occurs and is not detected by diver, and/or if emergency cylinder is not usable.	Use emergency cylinder or buddy breathe, if possible.	Should be detected on pre-dive check.
<u>Canister</u>						
Channels in Baralyme		Rectangular shape and consequent square corners.	Pellets can settle into corners after apparent filling, leaving voids in contents; pressure exerted by cap spring is not effective toward corners (sides) of canister; if pellets do not settle into corners, corners serve as channels: result is re- breathing of part of the un- scrubbed exhalation and inef- ficient use of Baralyme.	Fatal, as carbon dioxide in re-breathing system increases.	Use demand- breathing unit, if danger is realized.	Provide rounded edges or cylindrical canister, or redesign interior of canister so that exhalation flow is directed to the mass of Baralyme and does not approach corners.

TABLE 2. (Continued)

Part	Mode	Probable Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation/Remarks
<u>Canister</u> (Continued)						
	Canister used when empty or when containing exhausted Baralyme	Inadequate canister and effort required to remove from backpack for checking.	Checking of canister contents is not easy, but other than dependence on log entry or actual removal of filler cap, there is no other way presently to check the canister. This may result in use of an empty or partially filled canister, or of wet or exhausted Baralyme.	Fatal, as carbon dioxide in re-breathing system increases.	Use demand-breathing unit, if danger is realized.	Device is required that will indicate not only when canister is empty or partly full, but when Baralyme should be replaced. Two possibilities are 1. easy access view port, and 2. canister fabricated of one of the new, tough, hard-surface, transparent materials.
<b>Heating Jacket</b>						
Screws (attaching lower part of jacket to canister)	Leaking	Incomplete or broken seal due to improper application or rough handling.	Water into Baralyme with consequent shortened life.			Unlikely to occur suddenly in use. Prediver leak check of pressurized canister may detect.
Heating Blankets	Wire breakage	Inflation of blankets during rapid decompression.	Ineffectiveness of heating blanket in prolonging life of Baralyme.			Different type of electrical heating should be used.
Lead-ins to Blanket	Fraying, cutting	Lead-ins are not securely clamped to canister.	Cable motion will result in lead-in movement relative to the canister and heating jacket edge, wearing and fraying the lead-ins.	Electrical shock when touching canister.		Insulated clamp should be provided to anchor the lead-in.
	Pullout	Cable that attaches to umbilical is furnished with male and female plugs that are mated when blanket is not used; this resembles a handle.	Handlers and divers may tend to use handle-like plug configuration to lift apparatus with consequent pullout of electrical leads, barring the wires or disrupting current so that heating blanket is inoperative.	Ditto		Connection from blanket to umbilical should be redesigned and/or cable securely anchored to canister to prevent damage to wires.
Hot-Water Tubing	Bending, crimping, breaking of joint	Exposed position of tubing and drooping of canister.	Water passage will be plugged or open to the sea with result that water does not enter jacket, thus not heating Baralyme.			Will not occur during use, and should be visually apparent in prediver setup or check.
<b>Filler Cap</b>						
Spring Plate	Fines and powder in Baralyme	Filler plate, attached to spring, has tendency to turn as cap is screwed on.	Turning of plate, forced as it is against Baralyme, grinds the pellets and produces powder and small particles that may find their way into the gas stream.	Nausea from Baralyme dust.		Closure should be designed so that fragmenting force is not applied to Baralyme.
Spring	Breaking	Fatigue, mishandling.	Loss of compressive force against pellets with possible opening of voids within Baralyme mass and reduction in efficiency of canister.			Effect will be minor without complete disintegration of spring.
O-ring	Cracking, deterioration, cutting	Over age; solvent attack; pinching.	Leaking of gas to the sea or water into the canister with a decrease in effective use time of Baralyme.			Leak will be minor and probably undetected in prediver setup. O-rings should be inspected and replaced frequently and kept from solvent exposure.
Elbow (Street)	Leaking	Worn threads, looseness.	Gas will be lost to the sea.			Replace pipe threads and Teflon tape with straight thread connector and O-ring.

TABLE 2. (Continued)

Part	Mode	Probable Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation/Remarks
<u>Canister</u> (Continued)						
Connector	Leaking	Worn threads, looseness.	Gas will be lost to the sea.			Unlikely to occur suddenly in use, and should be detected in prediver setup.
	Ditto	Connector was not locked and inter-flow hose was tugged.	Gas flow to canister will be lost and water will enter canister.	Fatal	Use demand-breathing unit, or buddy breathe if possible.	Should be detected in prediver check.
O-ring (at sensor cap)	Cracking, deterioration, cutting	Over age, solvent attack, pinching.	Leaking of gas to the sea.			Unlikely to occur suddenly in use, and should be detected in prediver setup.
<u>Bag Attachments</u>						
	Cutting, cracking, deterioration	Hose clamps may cut the attachments and solvent attack may cause deterioration or cracking.	Ditto			Already leaking item will be detected in prediver setup. Elastomeric material should be checked frequently.
Hose Clamps	Breaking	Corrosion, overuse.	-			Although stamped "stainless", some clamps have rusted areas.
<u>Breathing Bags</u>						
Drain Caps	Leaking	Looseness, failure to secure.	Leaking of gas to the sea or water into the bags.	Increased breathing resistance through wet Baralyme; burns from inhaled water-Baralyme mixture.	Use demand-breathing unit.	Caps are located and attached inside vest pockets, making them difficult to secure to the bags and to check in prediver check.
<u>Breathing Hose Attachments</u>						
	Cutting	Hose clamps may cut the attachments as hoses or bags are flexed in handling.	Leaking of gas to the sea or water into the bags.	Ditto	Ditto	Already leaking item will be detected in prediver setup.
Hose Clamps	Breaking	Corrosion, overuse.	Ditto	-	-	Although stamped "stainless", some clamps have rusted areas.
<u>Canister Attachments</u>						
Appendages	Leaking	Hose clamps may cut the appendages as they or the bags are flexed in handling.	-	-	-	Already leaking item will be detected in prediver setup.
Threaded Couplers	Leaking	Worn threads; looseness.	-	-	-	Unlikely to occur suddenly in use, and should be detected in prediver check.
Hose Clamps	Breaking	Corrosion, overuse.	-	-	-	Although stamped "stainless", some clamps have rusted areas.
<u>Exhaust Valve Attachment</u>						
	Leaking	Hose clamp may cut the bag as use of exhaust valve causes flexure.	-	-	-	Already leaking item may not be detected in prediver setup, as flexure may be required to cause gas escape.
Hose Clamp	Breaking	Corrosion, overuse.	-	-	-	Although stamped "stainless", some clamps have rusted areas.

TABLE 2. (Continued)

Part	Mode	Probable Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation/Remarks
<u>Mouthpiece "T" Tube Assembly</u>						
Check Valve (inhalation)	Cracking, deterioration; cutting	Over age; solvent attack, mishandling.	Portion of exhaled gas may pass back into inhalation hose and be rebreathed on subsequent inhalation.	High carbon dioxide level in rebreathing system.	Use demand-breathing unit, if problem is realized.	Already failed. Item should be detected in pre-dive setup. Rubber item should be checked frequently and be kept from exposure.
Check Valve (exhalation)	Ditto	Ditto	Portion of exhaled gas may pass back into mouthbit on inhalation.	Ditto	Ditto	Ditto
Gaskets	-	-	Leakage of gas to sea. On inhalation, pressure in "T" body momentarily may be less than sea pressure with consequent entrance of water through failed gasket.	If water leaks, varies from discomfort to inability to use rebreathing apparatus.	Use demand-breathing unit.	-
Valve Retainer Ring	Cutting	Mishandling.	Valve may not completely shut off in the surface position with consequent possible leakage of water through mouthbit into "T" and exhalation hose.			Failure may not be detected in routine check of equipment.
Valve Lever	Breaking; bending	Dropping.	Valve cannot be operated if lever is missing or bent to a jammed condition.			Unlikely to occur in use, and will be detected in pre-dive setup.
Hose Clamps	Breaking	Corrosion; overuse.	Leakage of gas to the sea.			Although stamped "stainless", some clamps have rusted areas.
<u>Exhaust Valve</u>						
Diaphragm	Cracking; deterioration; cutting	Over age, solvent attack; mishandling.	Gas will leak constantly from exhalation bag. Leak may be great enough so that fresh gas passes through canister directly to exhalation bag.	Inability to breathe from the semiclosed system.	Use demand-breathing unit.	Unlikely to occur suddenly in use, although use of pull knob may increase a minor leak.
Valve Stem	Binding	Bending by mishandling.	Bind open - similar to leak above, bind close - rupture of breathing bags or leakage at diver-mouthpiece interface.	Ditto	Use demand-breathing unit or return to habitat or PTC.	Unlikely to occur suddenly in use, and should be detected in pre-dive setup or check.
Compression Spring	Breaking	Fatigue, mishandling.	Valve will unseat at lower pressure - may be difficult to build up system pressure.	-	Use demand-breathing unit.	Unlikely to be detected prior to failure.
<u>Vest</u>						
Bag Pockets	Tearing of bags	Tugging and pushing of bags to get them into pockets.	Leaking of bags with loss of gas and/or water into bag.	-	Ditto	Turn bag should be detected in pre-dive setup or check. Redesign pockets so that bags may be slipped in, toward the sides, with closure flap to retain bags in place.
Zipper	Pinching	No flap behind zipper.	Pinching of diver.	Minor injury to diver when securing vest.	Hold vest away from body while zipping shut.	Attach flap behind zipper to protect diver's chest.
Adjustment Straps	Pullout	Wear or rotting of thread.	Unbalance of backpack.	Difficulty in maneuvering.		Unlikely to occur. Normal inspections will detect worn fabric or thread.
Snaps	Spring breakage	Fatigue, corrosion, wear or deterioration of fabric.	Loose flap, insecure backpack.			Will not occur suddenly in use.
	Pullout	Ditto	Ditto			Ditto
Backpack Flap	Deterioration	Rubber coating; abrasion, salt water immersion and drying cycles.	-			-

TABLE 2. (Continued)

Part	Mode	Probable Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation/Remarks
<u>Demand-Breathing Unit (Titan II)</u>						
Connector (to control block)	Leaking	Connector not locked, and demand hose is tugged.	Gas is lost to the sea, demand unit is inoperative.	Inability to use demand- breathing unit.	Use semiclosed mode, or buddy breathe, if possible.	Should be detected in pre-dive check.
	Leaking	Worn threads, looseness.	Gas leak to the sea.	Ditto	Ditto	Will not occur suddenly while in use, and may be detected in pre- dive setup.
Female Hose Connectors	Leaking	Ditto	Ditto	-	-	Ditto
	Leaking	Worn hose ID, insecure hose clamp.	-	-	-	-
Cutoff Valve (Whitely)	Burst hose	Leak in demand line when Whitely valve is cut off.	Constant gas flow to the sea with possible drop in system pressure/flow be- low acceptable limit.	-	-	Remove cutoff valve from line, or replace Whitely valve with valve having pressure relief feature.
O-rings (In inlet valve assembly)	Cracking, deterioration	Over age, solvent attack.	Leaking of gas to the sea when Whitely valve is open, leakage of seawater into hose when Whitely valve is closed.			Will not occur suddenly in use, but unlikely to be detected in pre-dive setup or check. O-rings should be checked frequently and be kept from solvent exposure.
Valve Seat	Dirty, scored	Mishandling in assembly.	Gas leak through unit when Whitely valve is open.			Will not occur in use, and should be detected in postassembly check.
Poppet Stem	Bending	Ditto	Gas leak through unit when Whitely valve is open, or inoperation of unit due to jamming shut of the poppet.			Ditto
Poppet Spring	Breaking	Fatigue, mishandling.	Gas flow, once initiated, will continue as long as Whitely valve is open.			Prefailure detection is unlikely, although already failed item may be detected in pre-dive setup or check.
Demand Lever	Breaking or bending	Ditto	Demand unit will be inoper- ative, or breathing with it will be a great effort.	Difficulty in breath- ing, if unit is still operative.	Buddy breathe, return to habitat or PTC.	Prefailure detection is unlikely, but already failed item should be detected in pre-dive setup.
Diaphragm	Cracking, de- terioration, cutting	Over age, solvent attack, pinching.	Leakage of gas to the sea when unit is activated, sluggish operation, with intake of water into the case.	Difficulty in breathing.	Depress purge button to pro- vide constant, positive gas flow to clear the case and provide breathing gas.	Unlikely to occur suddenly in use, but may not be detected in pre-dive setup.
Purge Spring	Breaking	Fatigue, mishandling.	Demand lever may stay de- pressed with consequent steady outflow of gas.			Prefailure detection is unlikely, but already failed item should be de- tected in pre-dive setup or check.
Exhaust Valve	Cracking	Over age, solvent attack, mishandling.	Leakage of water into case, especially during inhalation.	Possible water ingestion.	Depress purge button to pro- vide constant, positive gas flow to clear the case and provide breathing gas.	Unlikely to occur suddenly in use, but may not be detected in pre-dive setup or check. Valve discs should be checked frequently and be kept from solvent exposure.
Mouthpiece Clamp	Breakage	Corrosion	Leakage of gas at mouthpiece-case inter- face, possible pull-off of mouthpiece from case.	Difficulty in using unit in emergency, if mouthpiece pulls off.		If severe rust occurs, clamp should be replaced.

TABLE 2. (Continued)

Part	Mode	Probable Cause	Possible Result	Possible Effect on Diver	Corrective Action	Recommendation/Remarks
<u>Breathing-Gas Lines</u>						
<u>Umbilical Hose</u>						
Hose	Cracking, cutting; deterioration; bursting	Over age; sharp bending and flexure; mishandling; solvent attack; overpressurizing; weathering.	Loss of external gas to system; leakage of emergency gas when cylinder is turned on.	Fatal, if not detected by diver.	Use emergency cylinder, return to habitat or PTC.	
Fittings	Looseness	Improper assembly, overpressurizing.	Leak of gas to the sea.	Ditto	Ditto	Threaded coupler looseness should be detected in prediver check. Loose hose fittings may be detected in prediver setup.
<u>Liter-Flow Hose</u>						
Hose	Cracking; cutting; deterioration; bursting	Over age; sharp bending and flexure; mishandling; solvent attack; overpressurizing; weathering.	Loss of gas to the rebreathing mode.	Anoxia, if not detected by diver.	Use demand-breathing unit or buddy breathing.	
	Kinking	Too-long hose used.	No gas out of control block to diver.	Fatal, if buddy breathing not available.	Buddy breathe, if possible.	Unlikely to occur and would be detected in prediver setup or check.
Fittings (Hansen)	Looseness	Inadequate crimp.	Leak of gas to the sea.	Fatal, if not detected by diver.	Use demand-breathing unit.	May not be detected in prediver setup unless hose is specifically checked.
<u>Demand-Flow Hose</u>						
	Cracking; cutting; deterioration; bursting	Over age; sharp bending and flexure; snagging; mishandling; solvent attack; overpressurization; weathering.	Constant gas flow to the sea if failure is on control block side of Whitney valve and if valve is closed. If failure is on other side of valve, water may enter hose if valve is closed but if valve is open, there will be constant flow to the sea.	Ditto	Buddy breathe, if possible.	Ditto
<u>Breathing-Gas Hoses</u>						
Inhalation Hose	Cracking, puncture, cutting; deterioration	Over age; snagging; cutting by hose clamp; solvent attack; weathering.	Leakage of gas to the sea; water into inhalation bag and/or mouthpiece by pumping action of breathing cycle.	Inability to breathe from the semiclosed system.	Use demand-breathing unit.	Prefailure detection is likely in prediver setup.
Exhalation Hose	Ditto	Ditto	Leakage of gas to the sea; water into exhalation bag; drop in system pressure as system tries to equalize pressure by gas flow through canister to exhalation bag.	Ditto	Use demand-breathing unit.	Ditto

TABLE 3. ENGINEERING ANALYSES/EVALUATIONS REQUIRED

Part	Analysis/Evaluation		Required	Performed
	Description			
Complete Apparatus	Weight distribution		Yes	No
Case/Cover Assembly	Best choice of material for design use		Yes	Yes
Emergency Cylinder	Pressure requirement		Yes	Yes
Valve Stem	Tangential force to bend/break		No	No
Pressure Regulator	Pressure reduction		Yes	Yes
	Pressure variance		Yes	Yes
Body-to-Dome Screws	Strength requirements		Yes	Yes
Control Block				
Block-to-Block Screws	Strength requirements		Yes	Yes
Orifices	Flow/pressure adequacy		Yes	Yes
Gas Passages	Ditto		Yes	Yes
Poppets	"		Yes	Yes
Demand Regulator	"		Yes	Yes
	Pressure variance		Yes	Yes
Sliding O-Rings	Groove diameter/depth versus retention		Yes	Yes
Connectors/Fittings	Pressure-resistance adequacy (strength)		Yes	Yes
Canister	Gas flow paths		Yes	Yes
	Flow adequacy		Yes	Yes
	Baralyme packing efficiency		Yes	No
Heating Jackets	Heat-transfer maximization		Yes	No
	Flow-rate capability		Yes	Yes
Spring Plate	Crushing force against Baralyme		Yes	No
Connectors	Pressure-resistance adequacy (strength)		Yes	Yes
Breathing Bags	Sufficient capacity to support breathing at various depths and work levels		Yes	No
	Capability to withstand "comfort" pressures		Yes	No
Mouthpiece "I" Assembly			No	No
Exhaust Valve	Sufficient range of relief pressures		Yes	No <sup>(a)</sup>
Valve Stem	Tangential force to bend/break		No	No
Vest			No	No
Demand Breathing Unit	Flow adequacy		Yes	Yes
Breathing-Gas Lines				
Main-Flow Hose	Flow/pressure adequacy		Yes	Yes
Liter-Flow Hose	Ditto		Yes	Yes
Demand-Flow Hose	"		Yes	Yes
Inhalation	"		Yes	Yes
Exhalation	"		Yes	Yes
Main-Flow Hose	Burst-strength adequacy		Yes	Yes
Liter-Flow Hose	Ditto		Yes	Yes
Demand-Flow Hose	"		Yes	Yes
Inhalation	"		No	No
Exhalation	"		No	No
Elbow Fittings	"		Yes	Yes
	Flow adequacy		Yes	Yes
Hose Fittings	Ditto		Yes	Yes
Quick Disconnects	"		Yes	Yes
Demand Cutoff Valve	"		Yes	Yes

(a) Relief pressure is set by the individual diver to his own satisfaction. Adequacy of range should be checked.

TABLE 4. PRESSURE/FLOW TESTS REQUIRED

Component/ Part	Test(a)	Performed
Emergency Cylinder	Pressure (proof)	Yes(b)
Valve	Flow	Yes(c)
	Leak	No
Pressure Regulator	Pressure (proof)	No(d)
	Pressure (reduction)	Yes(b)
	Flow	Yes(b)
Control Block	Pressure (proof)	Yes(e)
Orifice Assembly	Flow	Yes
Demand Regulator	Pressure (regulation)	Yes
	Flow	Yes
Purge Valve	Pressure	Yes
	Flow	Yes(c)
Canister	Pressure (proof)	Yes(b)
Water Jackets	Flow	Yes
	Temperature	Yes
Heating Blankets	Temperature	Yes
Breathing Bags	Pressure (proof)	Yes(f)
	Leak	Yes
Mouthpiece "T" Assembly	Flow	Yes(c)
	Leak	Yes(b)
Check Valves	Leak	Yes(g)
Exhaust Valve	Pressure (range)	Yes(g)
Demand Breathing Unit	Flow	Yes
	Leak	Yes
Breathing-Gas Lines	Flow	Yes(c)
Main-Flow Hose (w/ fittings)	Pressure (proof)	No
	Leak	Yes
Liter-Flow Hose (w/ fittings)	Pressure (proof)	No
	Leak	No
Demand-Flow Hose (w/ fittings)	Pressure (proof)	No(h)
	Leak	No(h)
Elbows	Pressure (proof)	No
	Leak	No(i)
Quick-Disconnects	Pressure (proof)	No(i)
	Leak	No(i)
Breathing Hoses	Leak	Yes

(a) Test to be applied to individual component/part, not only to representative QC sample.

(b) Test performed by supplier.

(c) Proved in use.

(d) "Functional" test by supplier. (5)

(e) Peak pressure of only 4500 psi reached. (7)

(f) Leak test at 1-1/2 psi.

(g) Predive setup or check.

(h) After installation of Whitely cutoff valve.

(i) Should be tested in situ.

TABLE 5. PHYSICAL TESTS REQUIRED

Part	Test	Purpose (To Prove)
Case/Cover Assembly	Drop (empty) Crush (empty)	To help set manufacturing standard Ditto
Pressure Regulator		
Inlet-Valve Spring	Fatigue	To suggest replacement schedule
Diaphragm Spring	Ditto	Ditto
Control Block	Pressure	To establish design maximum
Purge-Valve Spring	Fatigue	To suggest replacement schedule
Demand-Reg. Spring	Ditto	Ditto
Check-Valve Springs	"	"
Canister	Temperature profile (internal)	To suggest efficient design
	Flow profile(a)	Ditto
Electrical Lead-Ins	Flexure in seawater	Adequate strength and insulation
Breathing Bags	Accelerated environment	To determine resistance to in-use deterioration
Exhaust Valve		
Spring	Fatigue	To suggest replacement schedule
Demand Breathing Unit		
Purge-Button Spring	Fatigue	To suggest replacement schedule
Breathing-Gas Lines		
Main-Flow Hose	Accelerated environment	To determine resistance to in-use deterioration
Liter-Flow Hose	Ditto	Ditto
Demand-Flow Hose	"	"
Inhalation Hose	"	"
Exhalation Hose	"	"
Demand-Flow Hose	Flexure in seawater	"
Quick Disconnects	Pressure	To determine leak rate

(a) May require colored gas/smoke and transparent canister mock-up.

In general, the use of off-the-shelf items might not contribute to consistency unless each item taken "from the shelf" is carefully checked to insure that it exactly conforms to the previous "duplicate" item so far as material is concerned, not merely as to form, fit, and function. That is, an item "just as good as, or better than," another should not be accepted under any other condition than that this acceptance is a design change that is duly noted and approved by the accepting authority.

Items that are fabricated specifically for the apparatus likewise should be identified in detail. The terms "stainless steel" and "brass" are insufficient identification. The type of material, e. g., 304 stainless steel and cupronickel, 30 percent, should be specified.

As the subject of another task, engineering drawings of the Mark IX are being reviewed and prepared to MIL-D-1000 requirements. These drawings will include specific identification of all materials to be used in the fabrication of the Mark IX components. Thus, consistency will be maintained among the individual apparatuses that will be procured in the future.

### MAINTAINABILITY

The ease of maintenance and the amount and degree of required maintenance are, to some extent, indicative of design excellence or shortcomings. Maintainability includes not only the low need and the ease of replacing parts, but also the ease of care of the parts. And care of parts includes not only ease of adjustments, but also storability, ease of assembly, and cleanability, especially under field conditions.

The Mark IX apparatus, in general, has a high degree of maintainability. Parts, and even components, are easily replaced and adjustments are few and fairly simple. However, the apparatus is awkward to store in a protected condition so that (1) cleanliness and dryness are enhanced, (2) strain is not put on the breathing-gas lines, and (3) other items are not placed atop the unit. Also, the degree of cleanliness desirable for a breathing-gas system is difficult to achieve in the field. Assembly is easy, but both O-rings and thread sealant are required. These contribute directly to the problem of cleanliness.

The problem of storability is not precisely one of design of the apparatus. The Mark IX can be stored satisfactorily if a rack is designed specifically for the equipment.

The O-ring problem is one of O-ring lubricant rather than of O-rings, per se. Because there has been some concern about lubricants used in breathing systems, lubrication is treated extensively, below, apart from the problem of cleaning.

Cleaning is a three-fold problem in that compatibility of cleaning agent and material to be cleaned, effect of cleaning agent on the user, and effect of residual cleaning agent on the diver must be considered. Cleaning also is treated below.

### Lubrication

In the Mark IX apparatus, lubricant is used on all 20 O-rings and on the valve-seat gasket in the pressure regulator, and may be used on the threads of the canister filler cap. Thread sealant is used on fittings threaded into the pressure regulator, the control block, and the canister.

#### O-Ring Lubricants

The O-ring lubricants suggested for similar systems are Fluorolube grease (number unspecified)<sup>(8)</sup> and Fluorolube, Grade S-30.<sup>(9, 10)</sup>

Fluorolube is a series of chlorotrifluoroethylene polymers, including both oils and greases.<sup>(11)</sup> Grade S-30 is an oil. Both oils and greases are produced from the same base and all have the same chemical properties. The greases are produced by adding a silicon-based thickener. All Fluorolubes are compatible with oxygen and with brass and other metals except aluminum and magnesium. Hooker Chemical Corporation, producer of Fluorolube, does not specifically recommend them as O-ring lubricants, but leaves specific uses to the choice of the user.<sup>(12)</sup>

Depolymerization of the Fluorolubes results in the liberation of toxic gases. However, depolymerization of the chlorotrifluoroethylene polymer does not occur until the temperature exceeds 300 C (482 F), and the Fluorolubes are noted for their thermal stability up to 300 C.<sup>(11)</sup>

Voit Rubber Corporation instructs that all O-rings and threads in the Titan II demand breathing unit be lubricated lightly with Dow 4X or Dow Compound 3 silicone lubricant.<sup>(13)</sup> Both of these compounds are silicone greases, although Dow 4X also is available as an aerosol spray. Neither of these lubricants was designed for O-rings, but both are safe to use because they are inert to oxygen and compatible with most materials.<sup>(14)</sup>

NASA has approved the use of molybdenum disulfide powder (MIL-M-7866) for O-rings in breathing oxygen and breathing air systems.<sup>(15)</sup> The Bureau of Ships also approves molybdenum disulfide powder (Molykote Type Z Powder) for high-pressure air, oxygen, and dry, oil-free nitrogen systems, in addition to the Fluorolubes, Kel-F Grease No. 90, and other oils, greases, and dry-film lubricants.<sup>(16)</sup> Grove Valve and Regulator Company also recommends the use of Kel-F 90 on O-rings in the Mity-Mite pressure regulator.<sup>(4)</sup>

Fluorolube GR-544 (a grease), Fluorolube LG-160 (an oil), and Molykote Type Z powder are approved for use in oxygen- and nitrogen-gas piping systems.<sup>(17)</sup>

Apparently, then, there are several lubricants that should be acceptable for use in the Mark IX system. In choosing any lubricant, the major aspects that need to be considered are ease of application, ability to restrict application to the specific item needing lubricant, ease of removal in cleaning, and absence of toxic or undesirable compound formation in cleaning.

Regardless of which compound is used, the procedure is similar: the lubricant is to be worked into the O-ring and the excess is to be wiped off. Examination of Mark IX units indicates that this either is not being done or "excess" is capable of wide interpretation. However, contributing to lubricant buildup is the small size of the O-rings. It is difficult to "work in" lubricant and to remove the excess evenly. It is easier to lubricate larger O-rings and to avoid lubricant buildup on parts with which they come into contact.

A subjective comparison of the lubricant types is made in Table 6. However, a raw score based on this table will not indicate the best choice of lubricant type because of the differing importance of the categories and the differing likelihood of their occurring.

TABLE 6. COMPARISON OF O-RING LUBRICANT TYPES

Category	Type			
	Grease	Oil	Powder	Spray
Easier to apply	b	c	d	a
Easier to work in evenly	a	b	c	d
More likely to penetrate elastomer	b	a	c	d
Less likely to be applied in excess	d	b	c	a
Less likely for excess to enter system	b	c	d	a
Less likely to plug gas passages	d	c	b	a
Less likely to build up on contacting surfaces	d	b	c	a
Less likely for excess to pick up debris	d	c	a	b
More likely to hold O-ring in position	a	b	d	c
More likely to effect gas tightness	a	b	c	d
Easier to remove from contacting surfaces	d	c	a	b
Easier to remove from hidden areas	c	b	d	a
More conducive to cleanliness of area	a	c	d	b
More desirable in close-quarter use	a	b	c	d
Less likely to "soil" user	b	c	d	a

Note: The highest "rating" is a, the lowest is d.

All four types of lubricant are acceptable for use in the Mark IX system. However, the powder form of lubricant is most suitable, assuming that

- System cleanliness is of major importance
- Excess lubricant will be removed before the O-ring is installed
- O-rings will be lubricated and installed under confined, but clean, working conditions

- Lubricant already present will be removed insofar as possible if O-rings are replaced rather than renewed
- Use of organic solvent for cleaning contacting surfaces is undesirable.

Should the powder form of O-ring lubricant be chosen, the obvious choice is molybdenum disulfide. Should grease (a second choice) be used, either a fluorocarbon (Fluorolube, Kel-F 90, or other) or silicone (Dow 4X or Dow Compound 3) may be used. These greases are removable from metallic contacting surfaces with organic solvents. Although solvents, in themselves, may pose a health problem, the greases do not break down into toxic substances during normal cleaning. (12, 14)

#### Thread Sealant

Teflon tape (polytetrafluoroethylene) is approved for similar apparatus<sup>(10)</sup>, by the Bureau of Ships for high-pressure air, oxygen, and nitrogen systems<sup>(16)</sup>, and by NASA for breathing oxygen and breathing-air service.<sup>(15)</sup> However, such tape is to be used on pipe threads only. No lubricant is allowed on straight threads.

Polytetrafluoroethylene tape is not combustible in the presence of oxygen and does not produce toxic vapors at temperatures to 260 F. It is intended for use as an anti-seize and sealant on pipe threads in liquid and gaseous oxygen systems of 2000 psi and less. (18)

Teflon tape is acceptable for use on pipe fittings in the Mark IX system, that is, on the control block and at the liter-flow connection to the canister. However, Teflon tape shreds into strips and particles fairly easily, and these may fall into the control block where they, by themselves or in combination with excess O-ring lubricant, may affect gas flow. This danger may be eliminated by the use of straight-thread fittings and O-rings or gaskets as seals.

#### Cleaning

The only cleaning medium that is safe for the entire apparatus is clean, fresh water. Separate components may be cleaned with water-detergent solution, alkaline cleaning-compound solution, or organic solvents, but special precautions are necessary.

The use of organic solvents, because of their toxic and/or irritating fumes, must be restricted to well-ventilated areas. Also, a source of dry, oil-free compressed gas should be available to help evaporate the solvent and disperse any fumes.

The use of a cleaning compound, in a suitable nonorganic solvent, requires rinsing and flushing to insure that no caustic or otherwise irritating, harmful, or passage-clogging residue is left. In addition, the rinsing solvent, being nonvolatile, is apt to remain in passages in minute quantities.

Any solvent, and resultant cleaning residue, is apt to become trapped in blind areas within the apparatus. The concept of cleaning, therefore, must include removal of all residual cleaning agent and the thorough drying of equipment with oil-free air or nitrogen.

Similar apparatuses use trichloroethylene<sup>(9)</sup>, Freon PCA<sup>(10)</sup>, or nitric acid solution<sup>(10)</sup> for metallic cleaning and water-detergent (or soap) solution for nonmetallic cleaning. Besides being used for degreasing, trichloroethylene and ethyl alcohol are used as flushes to follow a water-detergent cleaning, water flushing, and gas drying sequence for metals.<sup>(19)</sup>

A most important consideration in the use of organic solvents, in addition to their use under controlled conditions, is the complete removal of residual solvent before the cleaned item is placed in service. Besides their effects on nonmetallic parts and components, residual solvents may have a toxic or debilitating effect on the user of the system. Trichloroethylene, in particular, although it is recommended for similar systems, is potentially dangerous for use with the Mark IX system.

Trichloroethylene evaporates rapidly (compared with carbon tetrachloride) and nausea and other side effects result from exposure to its vapors. It is very difficult to remove from confined spaces, even at temperatures near its boiling point.<sup>(20)</sup> When trichloroethylene is passed over alkaline materials at a temperature above 70 C (137 F), it produces dichloroacetylene, a very toxic vapor.\*

Residual trichloroethylene in the Mark IX system may pose a danger because of the presence of Baralyme (which contains alkaline material) and its exothermic reaction with moist carbon dioxide from the diver's breath.

Carbon tetrachloride also is a potentially dangerous cleaning agent. Kidney and liver failure can result from inhalation of the fumes, and swallowing one teaspoonful of the fluid can be fatal. Reportedly, "three thimblesful" of carbon tetrachloride can saturate the air in an unventilated room to the danger point.<sup>(22)</sup>

Various cleaning agents recommended for use in oxygen systems are listed in Table 7.

Before being placed in service, breathing-gas systems must be free of all loose scale, rust, grit, filings, oil, grease, and other foreign and/or organic materials.<sup>(23)</sup> Most of the cleaning agents listed in Table 7 do not actually clean, but serve only as degreasing solvents. Degreasing solvents do not remove particulate material such as metal chips and rust.<sup>(24)</sup>

The major metal components requiring cleaning in the Mark IX system are the Mity-Mite pressure regulator, the flow-control block, and the carbon dioxide-absorber canister. Both cleaning and degreasing are required for the pressure regulator and control block, while the canister requires only cleaning.

The regulator and control block, both disassembled with nonmetallic parts removed, should be degreased with Penolene or ethyl alcohol, immersed and agitated in a water-detergent solution, rinsed in fresh water, flushed with ethyl alcohol, and dried with oil-free, dry nitrogen. The canister should be cleaned with water-detergent solution (using a bottle brush through the filler port), thoroughly rinsed with fresh water, and dried with oil-free, dry nitrogen. Warming of the canister and/or gas during drying

\*For example, in one case, trichloroethylene was administered as an anesthetic in a closed-circuit system that used a soda-lime carbon dioxide absorber. The soda lime, reacting with the moisture and carbon dioxide in the patient's breath, became hot enough to convert trichloroethylene to dichloroacetylene.<sup>(21)</sup>

TABLE 7. CLEANING AGENTS FOR OXYGEN SERVICE

Cleaning Agent	For Cleaning (a)	Remarks
Trichloroethylene	Metals and Teflon (9, 12, 19, 20)	Vapors cause nausea; slow evaporation (20)
Ethyl alcohol	Nonmetallics (except Teflon) (12, 19)	
Freon PCA	Brass, stainless steel (10, 24)	Toxic vapor (24)
Nitric acid solution	Stainless steel (10, 19)	Liquid will cause burns
Trisodium phosphate (water soluble)	Metals (20, 23, 24)	Requires elevated temperature and wetting agent (24)
Water-detergent/soap solution	Plastics, rubber, materials (9, 10)	
Water	Plastics (8)	
Carbon tetrachloride	Metals (12, 20)	Vapors pose health hazard (22)
Trichlorotrifluoroethylene	Metals and approved Teflon (17)	Toxic decomposition product (17)
Chloroethene (1, 1, 1 trichloroethane)	Metals (20)	Corrodes metals in presence of water, decomposes at approx 212 F (20)
Oxylene M-6	Metals (20)	
Refrigerant 113	Metals (20)	
Freon 11	Metals (20)	Boiling point of 74 F (20)
Penolene	Metals (20)	Rapid evaporation; few side effects (20)
Metso 99 (water soluble)	Metals (20)	Attacks aluminum; tendency toward precipitation (20)
Diversey 909 (water soluble)	Metals (20)	
MIL-C-81302A (similar to Freon PCA)	Metals (24)	
MIL-C-8638	Delicate equipment (23)	

(a) "Metals" does not include aluminum or magnesium. Inhibitors and other precautions are necessary in cleaning these metals.

TABLE 8. CLEANING STEPS FOR MARK IX PARTS

Part	Cleaning Procedure(a)	Frequency
O-rings	Discard and renew	After each postuse disassembly or major overhaul
Mity-Mite Regulator		
Metal parts	Degrease with Penolene or ethyl alcohol, wash in water-detergent solution, rinse in fresh water, flush with ethyl alcohol, blow dry with oil-free, dry nitrogen	When O-rings or other internal parts are replaced
Diaphragm	Rinse in fresh water, nitrogen dry, or discard and renew(b)	Same as for O-rings
Seat seal	Ditto	Ditto
Flow-Control Block		
Metal parts	Same as for Mity-Mite	Same as for Mity-Mite
Seat seal	Discard and renew	When unit is cleaned
Canister	(1) Thoroughly rinse with fresh water, dry with oil-free, dry nitrogen (2) Clean interior with bottle brush and water-detergent solution, rinse thoroughly with fresh water, blow dry with oil-free, dry nitrogen; or immerse in mild water-detergent solution in ultrasonic cleaning tank, rinse, and dry as above	After each use Periodically - schedule should be set dependent upon use
Breathing Bags	Thoroughly rinse with fresh water, hang to drain or blow dry with nitrogen	After each use
Breathing Hoses	Same as for breathing bags	Same as for breathing bags
Rebreathing Mouthpiece	Rinse insides with fresh water, hang to drain or blow dry with nitrogen	After each use
Metal parts	Wash in water-detergent solution, rinse in fresh water, flush with ethyl alcohol, blow dry with oil-free, dry nitrogen	After each postuse disassembly or major overhaul
Nonmetallic parts	Rinse in fresh water and nitrogen dry	Ditto
Exhaust Valve	Same as for breathing bags	Same as for breathing bags
Metal parts	Same as for rebreathing mouthpiece parts	Same as for mouthpiece
Rubber parts	Ditto	Ditto
Vest	(1) Rinse in fresh water, hang to dry (2) Wash in water-detergent solution, rinse in fresh water, hang to dry	After each use Periodically - schedule should be set dependent upon use
Backpack	Rinse thoroughly in fresh water, wipe case dry, blow dry with nitrogen the hidden areas behind metal parts	After each use
Gas Hoses		
Umbilical hose	Thoroughly rinse with fresh water, hang to dry or blow dry with nitrogen	When detached from control block
Liter-flow hose	Ditto	After each postuse disassembly
Demand-flow hose	"	Ditto
Demand-breathing unit	Rinse externally with fresh water, hang to dry	After each use
Metal parts	Same as for rebreathing mouthpiece parts	Same as for mouthpiece
Nonmetallic parts	Ditto	Ditto

(a) Verdigris or encrustation may be removed from exterior surfaces of metals by careful cleaning in 15 to 20 percent nitric acid solution.

(b) Grove recommends that all soft goods be replaced at the same time, i.e., when O-rings are replaced, diaphragm should be replaced.

is desirable. However, no organic solvent - particularly not trichloroethylene - should be used in the canister.

The nonmetallic parts and components of the Mark IX apparatus should be rinsed only in clean water and dried with oil-free, dry nitrogen. Other metallic parts may be cleaned in a water-detergent solution or, if encrusted with verdigris, carefully cleaned with a 15 to 20 percent nitric acid solution, both methods followed by thorough rinsing, flushing with ethyl alcohol, and drying in oil-free, dry nitrogen.

Not only must the equipment be cleaned, but steps must be taken to prevent recontamination during handling, transportation, assembly, and storage. (20) Cleaned parts should be protected by plastic bags or, if assembled, all openings and ports should be capped.

Suggested cleaning steps for Mark IX components are summarized in Table 8.

The use of hose clamps to secure breathing-gas hoses to the mouthpiece and to the breathing bags, as well as to secure the exhaust valve in the exhalation bag, practically insures that these items will be handled as a unit. Aside from awkwardness and the possibility of snagging or uneven strain, this arrangement does not seriously affect normal postdive cleaning. All of these components are to be cleaned only with fresh water, and drain drying is adequate.

The use of Teflon tape on pipe fittings in the control block may discourage complete disassembly for cleaning. Ordinarily, postdive cleaning of the control block, except for inspection of the orifice/screen assembly, is unnecessary. However, when the block is disassembled for cleaning, the umbilical hose must be removed and cleaned separately.

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